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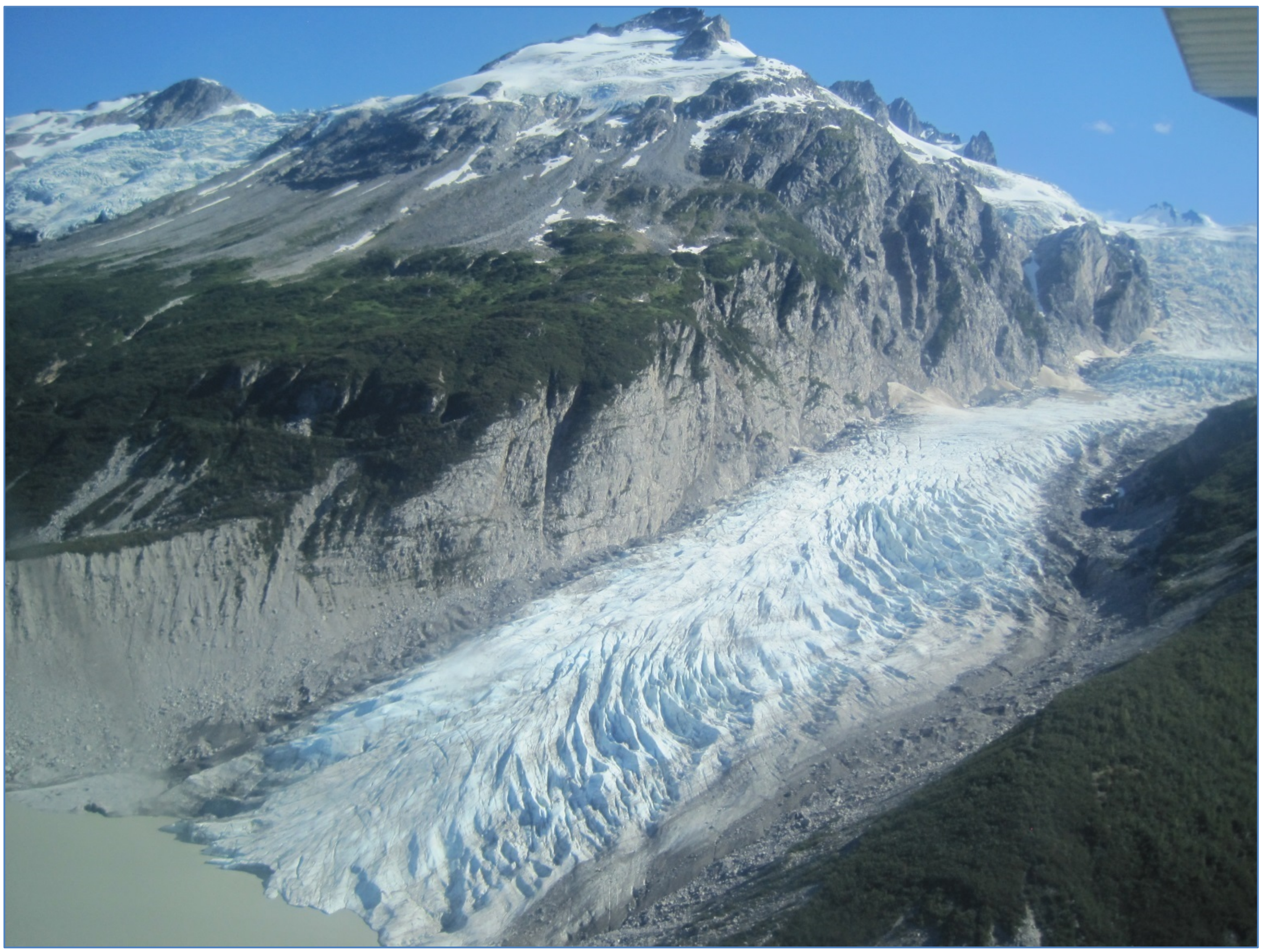
Natural Resource Stewardship and Science

Image interpretation and Classification of Land Cover Change in Lake Clark and Kenai Fjords National Parks Between 1954 and 2009

Natural Resource Report NPS/SOPN/NRR—2014/866

Pacific Northwest Cooperative Ecosystem Studies Unit (PNW CESU) Cooperative and Joint Venture Agreement H807110001, *Task Agreement P12AC15013*.



ON THE COVER
Lake Clark Pass, Lake Clark National Park and Preserve, Alaska
Photograph courtesy of Mr. Chuck Lindsay, NPS Alaska Region.

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Abstract

This collaborative project was completed with cooperative involvement and expertise from the National Park Service and Saint Mary's University of Minnesota's GeoSpatial Services program. The goal of the project was to develop historical spatial datasets to assist the Southwest Alaska Network (SWAN) in identifying and classifying on-going landcover changes occurring in Lake Clark National Park and Preserve and Kenai Fjords National Park.

Changes occurring in the natural environment have important consequences for ecosystem function and natural resource management. Historical aerial photography of many national lands was completed in Alaska during the 1950s. These images provide a point-in-time record of existing natural conditions. For this project, these older aerial photographs were converted to digital format then compared to remotely sensed imagery captured in the 1980s and 2000s as well as other thematic layers using a geographical information system (GIS). The effort to map landcover and landcover change over three time steps was completed using heads-up interpretation techniques by a skilled image analyst in a fully digital environment.

A hybridized National Land Cover Dataset (NLCD) model was developed and used for classification of unique and regional features. Seven areas of interest, four in Lake Clark National Park and Preserve and three in Kenai Fjords National Park, were selected for study. The mapping project accomplished the objective to complete delineation and classification of land cover from three different time steps in over 170,000 acres of seven different areas of interest. This inventory data provides an important baseline dataset for future landcover change analysis, monitoring, and management activities.

The resulting mapping products record landcover extent and classification for three different time periods spanning mid-1950 through 2009. Change classes were also delineated for each of the time periods mapped: 1950s-1980s, 1980s-2000s, and 1950s-2000s. Approximately 170,000 acres were mapped and classified using traditional image interpretation techniques. Challenges encountered were typical of any photo interpretation exercise and included: image resolution and quality, base map shifting as a result of orthorectification processes, limited availability of field-based collateral data for decision support, changes in image emulsion, diversity of the natural environment across project study areas, and the overall scope of potential landcover change types.

Changes in landcover have important implications for ecological function and biodiversity. The information gathered for this project will benefit natural resource management efforts in LACL and KEFJ as conservation professionals seek to understand natural and anthropogenic forces affecting the nation's national parks. Analysis of these data may assist park staff in identifying driving patterns of land cover change in the region such as vegetation cover, surface hydrology, fire regime, erosion and deposition, subsidence, uplift, and glacial extent.

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List of Acronyms

AHAP – Alaska High Altitude Aerial Photography Program

AOI – Area of Interest

CIR – Color Infrared

DOQQ – Digital Ortho Quarter Quad

GIS – Geographic Information Systems

GLOF – Glacial Lake Outburst Flow

KEFJ - Kenai Fjords National Park

LACL – Lake Clark National Park and Preserve

MMU - Minimum Mapping Unit

MRLC - Multi-Resolution Land Characteristics Consortium

NASA – National Aeronautical and Space Administration

NLCD – National Land Cover Dataset

NPS – United States National Park Service

SDMI – Alaska Statewide Digital Mapping Initiative

STATSGO – State Soil Geographic Database

SWAN – National Park Service Southwest Alaska Network

TIFF – Tagged Image File Format

USGS – United States Geological Survey

Introduction

Background

The Southwest Alaska Network (SWAN) of the National Park Service Alaska Region has assembled spatial datasets which are valuable in the examination of long term, landscape-scale changes in its constituent parks. Historic aerial photography is one such dataset and represents an important point-in-time record of landscape conditions. This photography continues to be useful when changes in landscape including vegetative cover, surface hydrology, fire regime, subsidence, uplift, erosion and deposition, or glacial extent are considered. When converted to digital form and combined with other remotely sensed data or thematic layers in a geographic information system (GIS), interpretation of historical imagery provides land managers with additional analysis tools. The data from this project is intended to inform the design and implementation of SWAN monitoring programs and to facilitate natural resource management decisions.

Between 2008 and 2011, SWAN staff worked with SMUMN GeoSpatial Services to georeference and orthorectify historic aerial imagery for Lake Clark National Park and Preserve (LACL) and also Kenai Fjords National Park (KEFJ). The resulting geospatial products included complete image coverage of LACL and KEFJ units for two points in time; circa 1954 and circa 1985. The orthorectified data products also met the National Map Accuracy Standard for 1:63,360 scale imagery. The completed products were combined with other spatial data layers (such as IKONOS satellite imagery circa 2005 - 2009) for the purposes of assessing landcover change over time as part of this current project.

The NPS initially considered 19 areas of interest (AOIs) for possible assessment in this project. The final AOIs selected for this project included approximately 170,000 acres in seven portions of LACL and KEFJ parks. Using the funding available through this task agreement, SMUMN worked with the NPS to interpret, classify, and delineate land cover change for seven AOIs. The AOIs were Caribou Lakes (LACL), Chinitna Bay (LACL), Lake Clark Pass (LACL), Tuxedni Bay (LACL), Aialik Bay Ranger Station (KEFJ), Bear Glacier Outburst Flood Source (KEFJ), and Northeastern Glacier (KEFJ).

Image interpretation and heads-up digitizing of land cover classes was completed for three time periods; 1954, 1985 and 2009. Changes in landcover classifications were also delineated for three time periods: changes noted between the 1954 and 1984 imagery, changes noted between the 1984 and 2009 imagery, and changes noted between 1954 and the 2009 imagery. As image quality improved over the 1954-2009 time span due to advances in sensor technology, interpreted land cover classes from each time step documented progressively more detailed information about change such as: dominant species composition, canopy closure, and associated physical or anthropogenic processes.

The classification hierarchy used in this project was based on the National Land Cover Dataset (NLCD) model which was also hybridized to accommodate data that was of special interest to the NPS and others where possible (e.g., subclasses for talus, landslides, and volcanic ash were included under the NLCD Barren class).

A hierarchical classification of land cover change was derived from interpretations for each individual time step such that changes over time were characterized at several levels. For example, the transition from barren glacial outwash (as noted in photography taken in 1954) to alder (as noted in satellite imagery captured in 2009) was simultaneously classified as "barren to shrub" and "shrub establishment". Potential change classes were expected to include vegetation change (e.g., shrub establishment, shrub closure, spruce expansion) as well as geomorphic change (e.g., glacial retreat, channel migration, pond drying, mass wasting); often occurring in concert. The development of change classes and creation of the associated spatial geodatabase was an iterative effort requiring continuous collaboration between regional experts from the NPS and image analysts from SMUMN.

Saint Mary's University of Minnesota was uniquely qualified to complete this work for the NPS due to prior collaboration on other image interpretation projects. SMUMN's staff has an extensive history of interpretation of natural ecosystems and land cover using aerial and satellite imagery in Alaska. These imagery projects have spanned most of Alaska's major geographic regions and have included a diversity of image types, classification systems, and ecological units. Projects have included:

- Delineation of NWI map units for Glacier Bay National Park (GLBA);
- Conversion of National Vegetation Classification System polygons to digital form for KEFJ;
- Interpretation of Alaska Vegetation Classification System cover types for off highway vehicle access trails in Wrangell-St. Elias National Park and Preserve;
- Image interpretation of shallow lake ecosystems and open water changes for Yukon Charley National Preserve.

The NPS was substantially involved in this project and worked directly with SMUMN to identify and resolve problems associated with image interpretation and classification over the course of the Task Agreement. Such collaboration was required because of differences in data quality for imagery captured at different points in time and potential technical or mapping issues.

The application of a variety of types of aerial and satellite imagery in this project (**Table 1**) was expected to introduce novel issues relating to image interpretation, hierarchical land cover classification, ecosystem change and documentation of natural and anthropogenic processes affecting park resources. For this reason, staff from SWAN collaborated with SMUMN to develop approaches, validate image interpretation results, discuss interpretation and classification alternatives, and to document image interpretation issues for future mapping consideration of other areas. SWAN scientists also provided ancillary data (e.g., oblique photos and data summaries from field plots) as well as regional expertise to aid in the image interpretation and classification for this project.

Completed data products from this project are expected to be used by independent educators and researchers seeking to better understand the effects of geomorphic change, post glacial processes, and regional climate change. For example, similar data products (e.g., time series of orthorectified air photos produced under a separate Task Agreement with SMUMN) have recently been requested by a researcher seeking to delineate historic fire scars in the boreal-transition zone of northern Lake Clark. The development of methods to interpret change on the landscape is also expected to be of interest to partnering agencies (such as USFWS, USFS) as well as other public entities interested in management of natural resources. These agencies might include non-governmental organizations monitoring key watersheds such the Cook Inlet watershed.

Table 1. Summary of Photography and Satellite Image Characteristics.

Park	Years	Emulsion	Scale
LACL	1952-57	B/W	1:40,000
	1978-80	CIR	1:63,000
	2005-09	IKONOS*	IKONOS*
	2011	SPOT5**	SPOT5**
KEFJ	1950-52	B/W	1:40,000
	1984-85	CIR	1:63,000
	2005-09	IKONOS*	IKONOS*
	2010	SPOT5**	SPOT5**

B/W = Black and White;

CIR = Color Infrared.

**IKONOS satellite imagery provided by the NPS; the scale is adjustable.*

***SPOT5 satellite imagery obtained through the Alaska SDMI; the scale is adjustable*

Project Study Areas

Approximately 170,000 acres were mapped and classified for this project in two of the nation's national parks. This included select locations comprising seven areas of interest (AOI). Four AOIs were located within LACL (Caribou Lakes, Chinitna Bay, Lake Clark Pass, Tuxedni Bay), and three AOIs were located in KEFJ (Aialik Bay RS, Bear GLOF Source and Northeastern Glacier).

Lake Clark National Park and Preserve

Located along Cook Inlet in southwestern Alaska, LACL was first established in 1978 by executive order as a national monument and gained national park status under the Alaska National Interest Lands Conservation Act (Public Law 107-282) in 1980 (**Figure 1**). The administrative headquarters for the park are found approximately 100 miles to the northeast in the city of Anchorage. Field headquarters and the main visitor's center are located in the town of Port Alsworth along the shores of the park's signature lake. The park contains a variety of habitats including tundra, coastal forest, and riparian wetland ecosystems in its interior. Both the Kvichak and Nushagak Rivers flowing into Bristol Bay have their headwaters in LACL. This park's numerous lakes, rivers, and streams protect the water quality and significant portions of the headwater spawning grounds for salmon stocks within the Bristol Bay watershed (NPS, 2009).

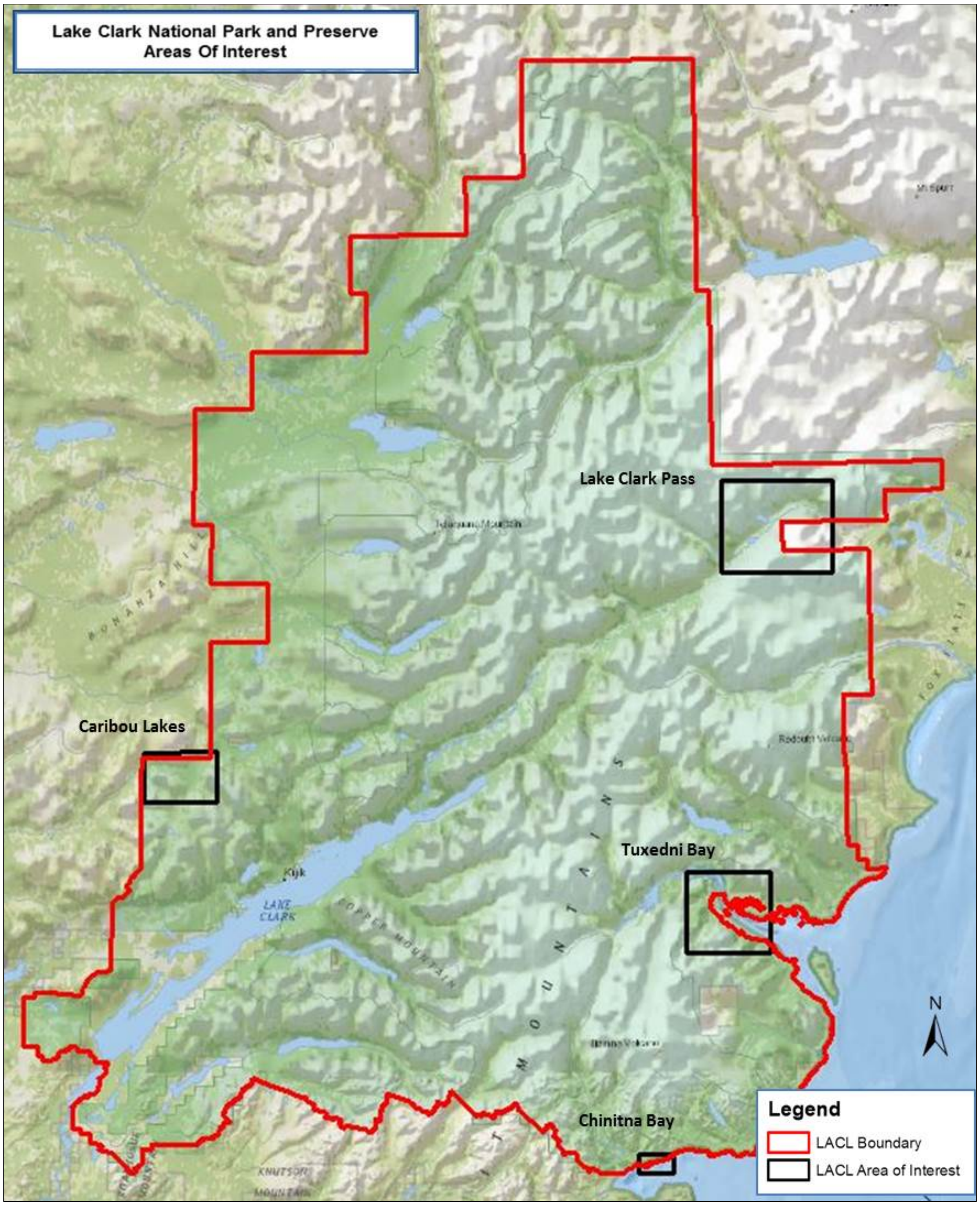

Figure 1. Park boundary and location of AOIs in LACL.

The park is committed to protecting, "unaltered watersheds supporting Bristol Bay red salmon, and habitats for wilderness dependent populations of fish and wildlife, vital to 10,000 years of human history" (NPS, 2009). LACL's four million acres include the northern end of the Alaska Peninsula in south central Alaska. The park straddles the Chigmit Mountains bridging the Aleutian Range to the southwest and the Alaska Range to the north. Mountainous terrain rises from the coastline of western Cook Inlet, framed by rugged peaks and spires, glaciers, and snow clad volcanoes. West of the mountains lies a region characterized by braided glacial rivers, cascading streams, waterfalls, turquoise lakes, boreal forest and tundra.

Caribou Lakes AOI

The Caribou Lakes AOI included approximately 25,000 acres and is located along the western border of LACL National Preserve. This area of interest (AOI) is found approximately 20 miles northwest of the LACL Port Alsworth Visitor Center. The area includes a complex of freshwater rivers, lakes and groundwater systems; the lakes created from past glacial retreats (**Figure 2**). Vegetation of the area is characterized by shrublands and lichen.

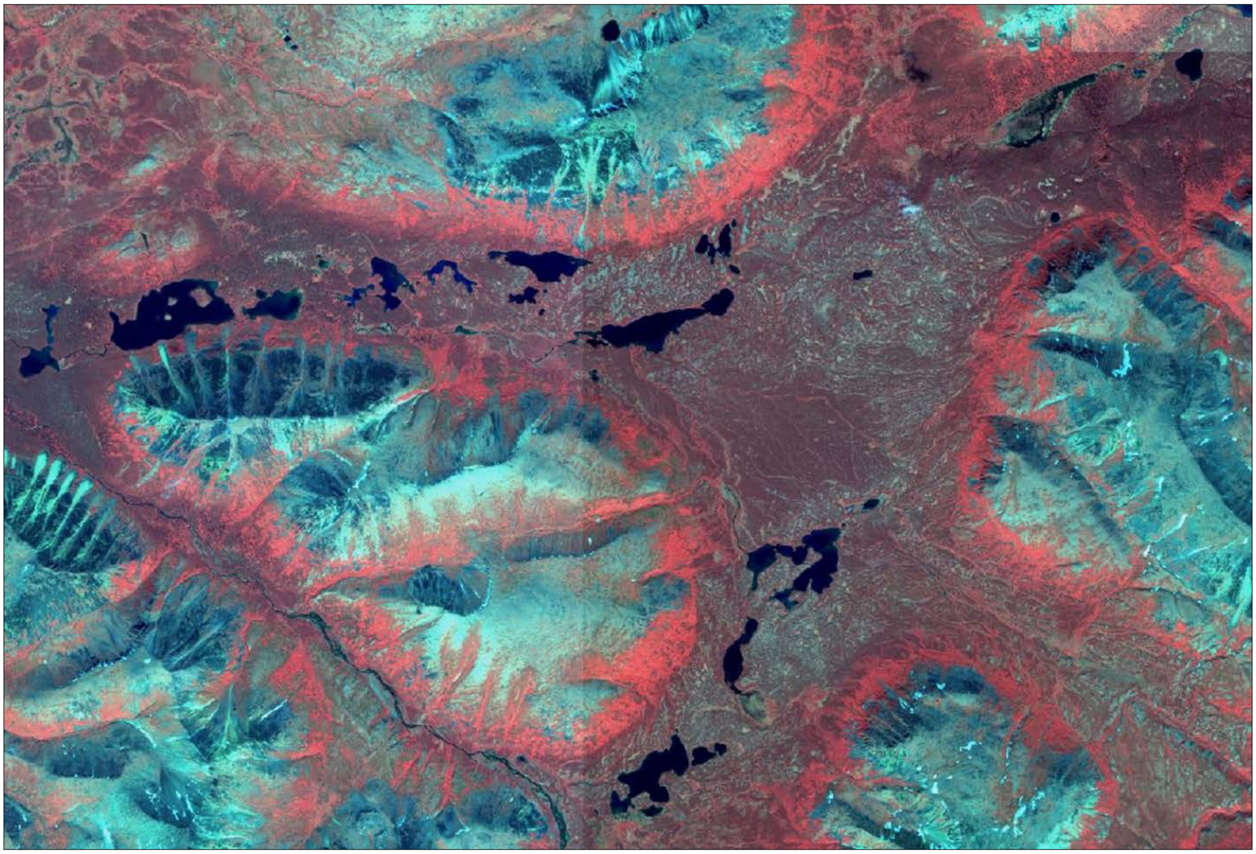

Figure 2. Caribou Lakes AOI, LACL National Preserve, IKONOS CIR imagery, 2005-2009.

Chinitna Bay AOI

One of the selected areas in LACL included approximately 4400 acres near Chinitna Bay. This area of interest (AOI) is located on the southern boundary of LACL; approximately 45 miles southeast of Port Alsworth below Horn Mountain and near the entrance to Cook Inlet. The coastline of Chinitna Bay is characterized by sand and gravel with patches of conifers. The interior is marked by green meadows of rye grass and young spruce surrounded by both brackish and freshwater marshes. This area offers scenic meadows and bear viewing along the beach (**Figure 3**).

Figure 3. Chinitna Bay AOI, LACL, IKONOS CIR imagery, 2005-2009.

Lake Clark Pass AOI

The Lake Clark Pass AOI (**Figure 4**) is found approximately 70 miles northeast of Port Alsworth. The area includes 70,110 acres of steep rugged glaciated mountains and glacier valleys generally located between the Neacola and Chigmit mountain ranges (sub ranges of the Aleutian Range). The pass is at an elevation of 1,050 feet above sea level and more than 9,000 feet below the peak of Mt. Redoubt, towering over the pass to the south. Lake Clark Pass is also a primary aviation route between south central Alaska (including Anchorage) and western Alaska. The Lake Clark Pass follows a large fault running from the Cook Inlet Basin to the southwest, under Lake Clark itself.

This AOI was mapped as one ecological subsection, even though it spans two ecoregions. This is due to its importance as an ecological corridor. Large valley glaciers have filled the pass many times; pushing out west into the area occupied by Lake Clark, southwest to Iliamna Lake and also west up the Chulitna River. In the early 1960's ice blocked the head of the pass from two side valley glaciers. Moraines and glacial till cover the sides and floor of the pass and associated valleys. Till plains, morainal remnants and outwash deltas cover the terrestrial portions of the subsection south and west Lake Clark Pass (NPS, 2001).

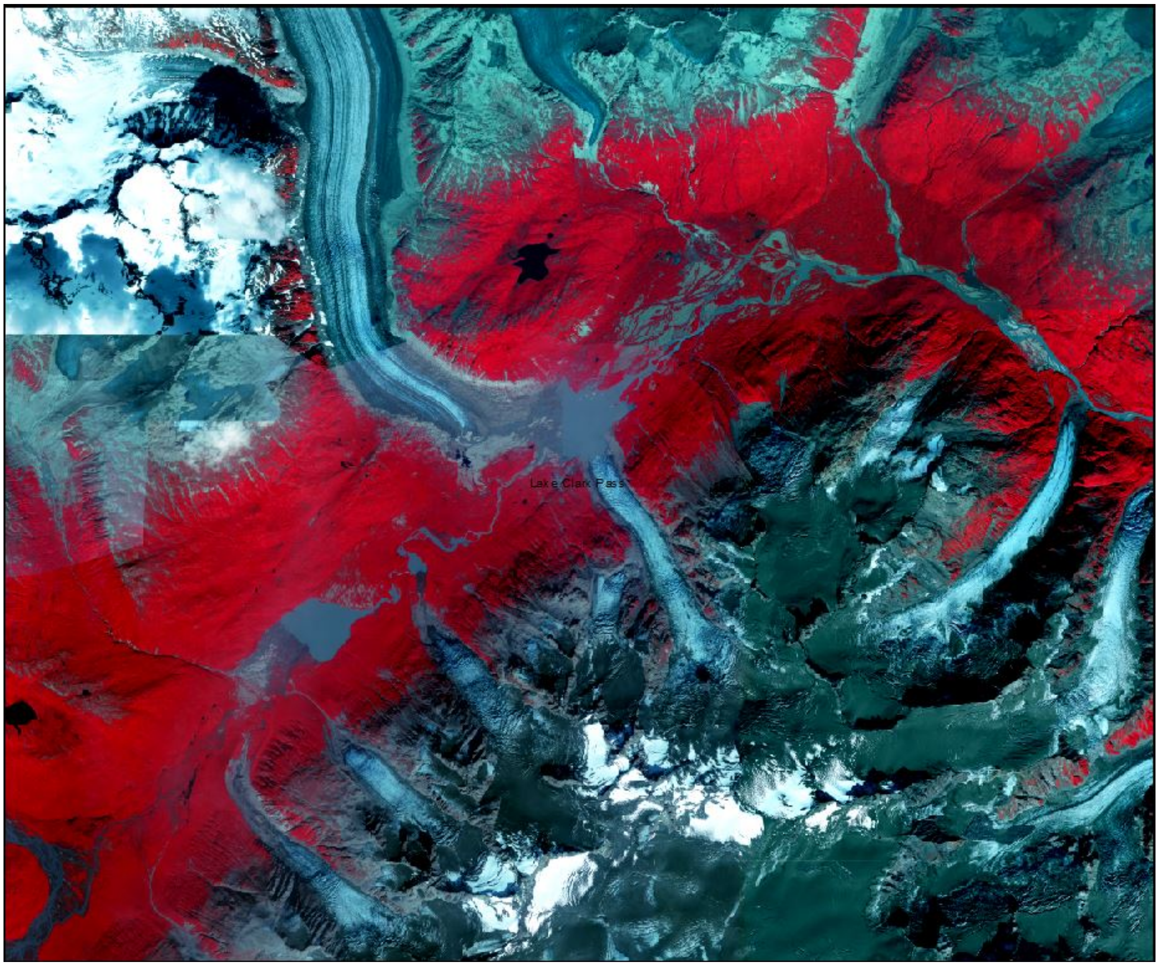

Figure 4. Lake Clark Pass AOI, LACL, IKONOS CIR imagery, 2005-2009.

Tuxedni Bay AOI

Tuxedni Bay is on the west side of Cook Inlet, approximately 50 miles east of Port Alsworth. This AOI includes approximately 47,200 acres. This region of rugged mountain terrain was carved by glaciers and has deep river canyons draining into the tidal flats at the head of the Bay. Glacial outwash creates a series of meandering rivers and streams to the valley below where it meets with the braided Tuxedni River (**Figure 5**).

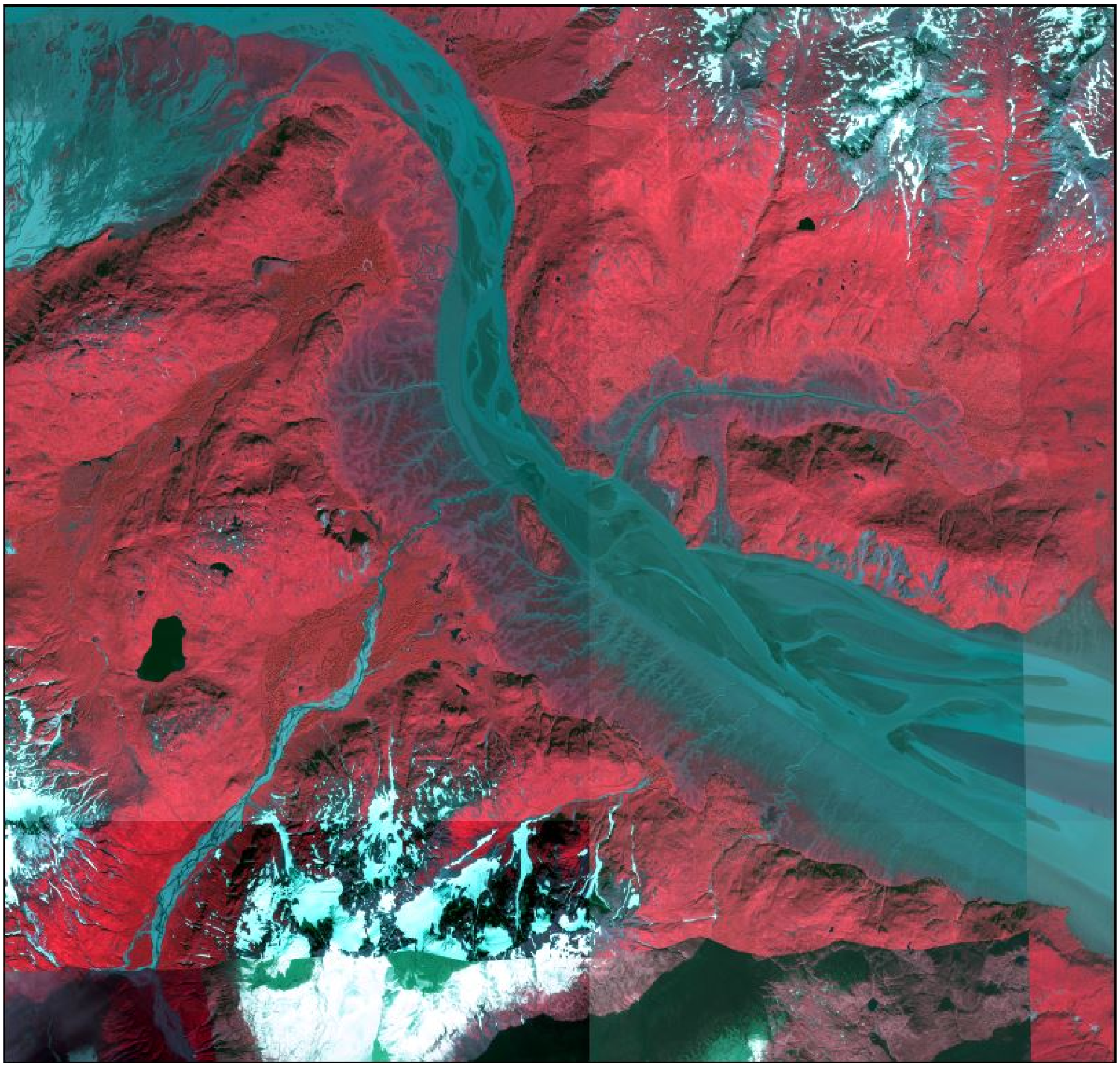

Figure 5. Tuxedni Bay AOI, LACL, IKONOS CIR imagery, 2005-2009.

Kenai Fjords National Park

KEFJ is located on the southeastern Kenai Peninsula near the community of Seward. This park contains approximately 65% of the Harding Icefield; the largest icefield that resides completely within the United States.

The Gulf of Alaska coast forms the eastern boundary of the park. Positioned at the edge of the North Pacific Ocean, this park of approximately 669,984 acres is exposed to extensive storms and significant precipitation. Annual snowfalls of 400 to 800 inches feed over 38 glaciers that flow outwards from the Harding Icefield. Terrain within the park is extremely rugged and elevations range from sea level to +/- 6000 feet; often within very short horizontal distances.

Kenai Fjords National Park derives its name from the Norwegian word for “fingers.” Long, steep-sided, glacier carved valleys are the result of seaward ends from the Kenai Mountains, slipping into the sea then dragged under by the collision of two tectonic plates of the Earth's crust. As a testimony from the last ice age, Harding Icefield is the park’s dominant feature and includes 300 square miles of heavily glaciated icefield. Nearly 40 other glaciers also flow from Harding Icefield.

Three AOIs within KEFJ park were selected (**Figure 6**) including Aialik Bay Ranger Station (Aialik Bay RS), Bear Glacier Outburst Flood Source (Bear GLOF Source), and Northeastern Glacier.

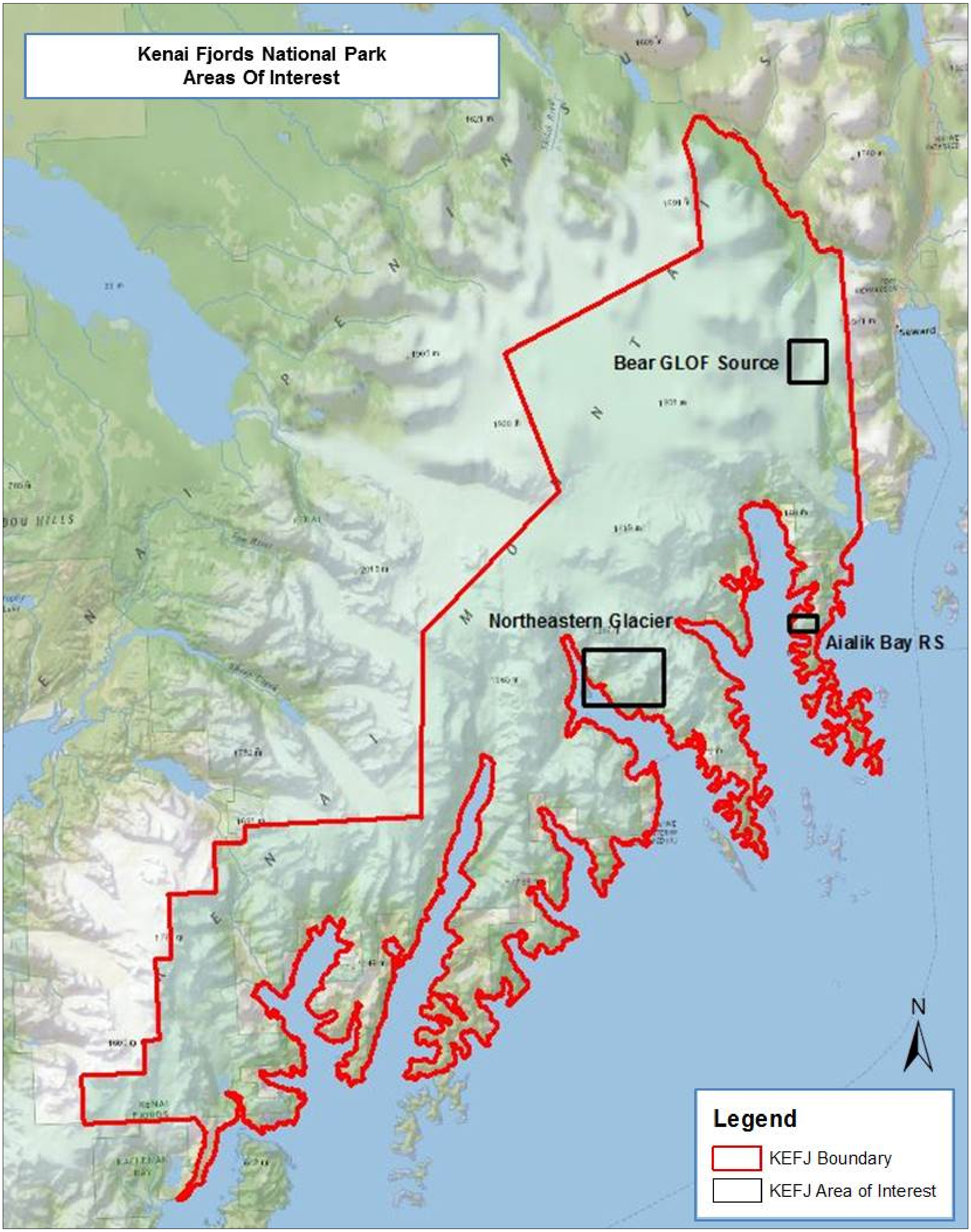

Figure 6. Park boundary and selected AOI locations in KEFJ National Park.

Aialik Bay RS

The Aialik Bay Ranger Station (Aialik Bay RS) AOI (**Figure 7**) is located approximately 20 miles southwest of Seward, Alaska and includes approximately 3,600 acres. This previously glaciated area exhibited diversified vegetative communities such as herbaceous uplands, alder, and spruce.

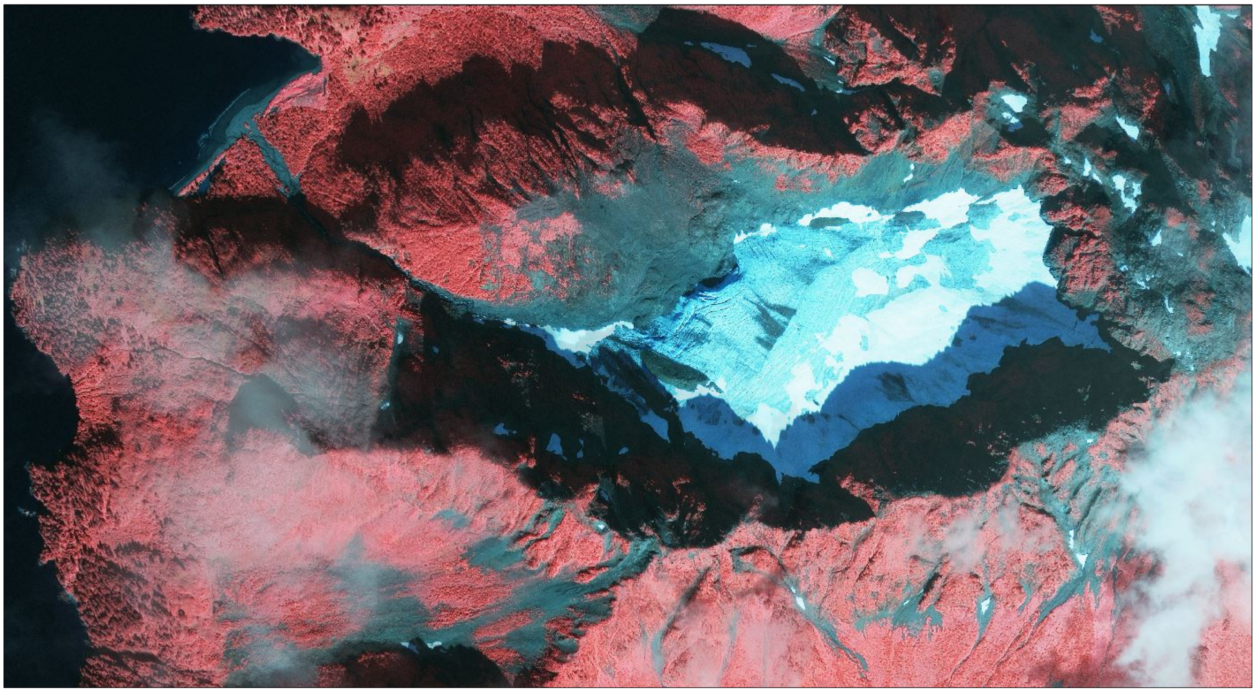

Figure 7. Example of Aialik Bay RS AOI, IKONOS, CIR imagery, 2005-2009.

Bear GLOF Source AOI

The Bear Glacier Outburst Flood Source (Bear GLOF Source) AOI is located approximately six miles west of Seward, Alaska. The area is remote, rugged, and glaciated and includes approximately 3,800 acres (**Figure 8**).

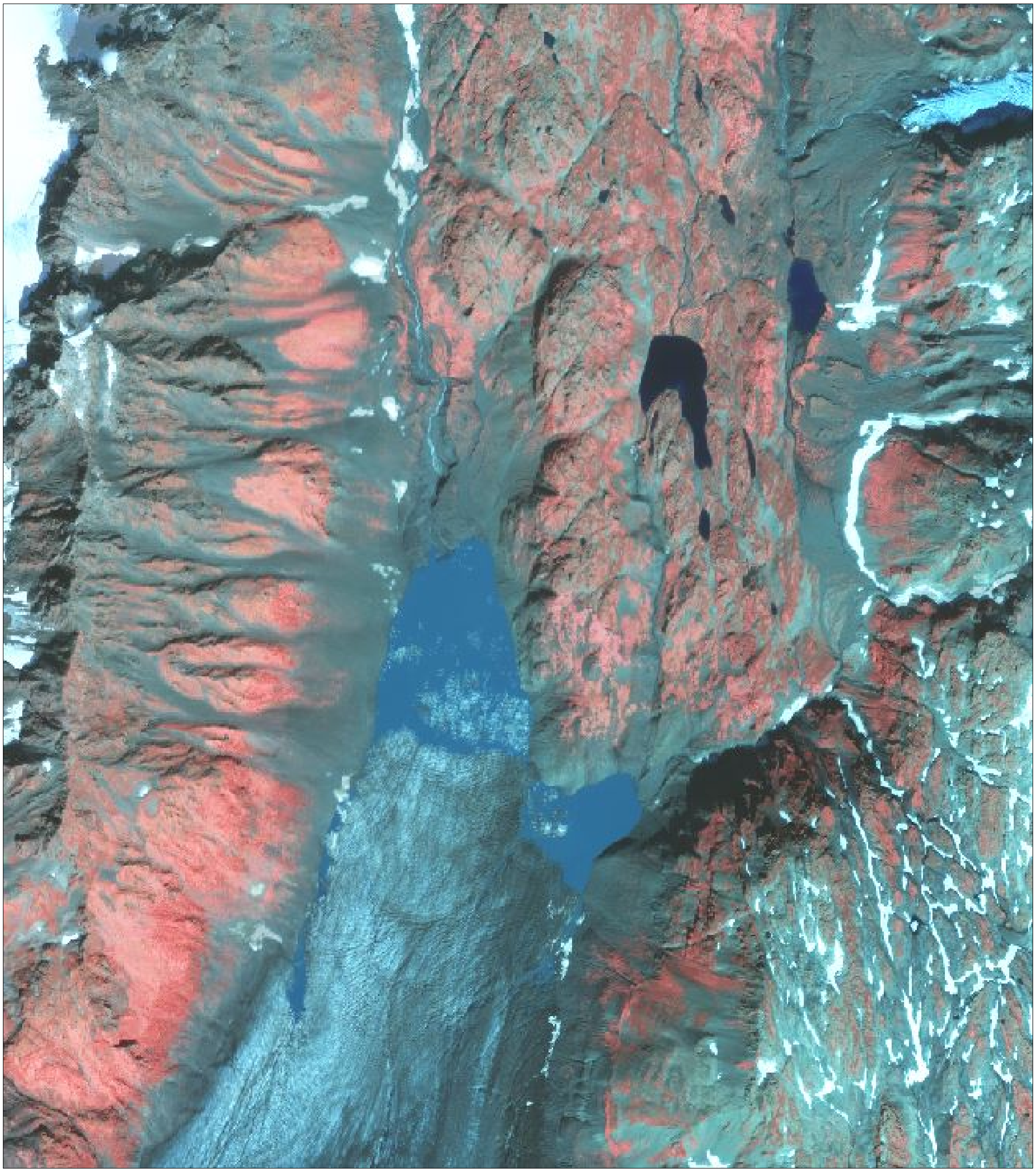

Figure 8. Bear GLOF Source AOI, KEFJ, IKONOS CIR imagery 2005-2009.

Northeastern Glacier

This area within KEFJ National Park is located approximately 25 miles southwest of Seward, Alaska. The Northeastern Glacier AOI includes approximately 11,300 acres and is located in a mountainous area where vegetation cover is high. Dwarf shrub and scrub vegetation blankets the sloped mountainsides while expanses of alder (*Alnus sp.)* are commonly found in the glacially carved valleys of this region (**Figure 9**).

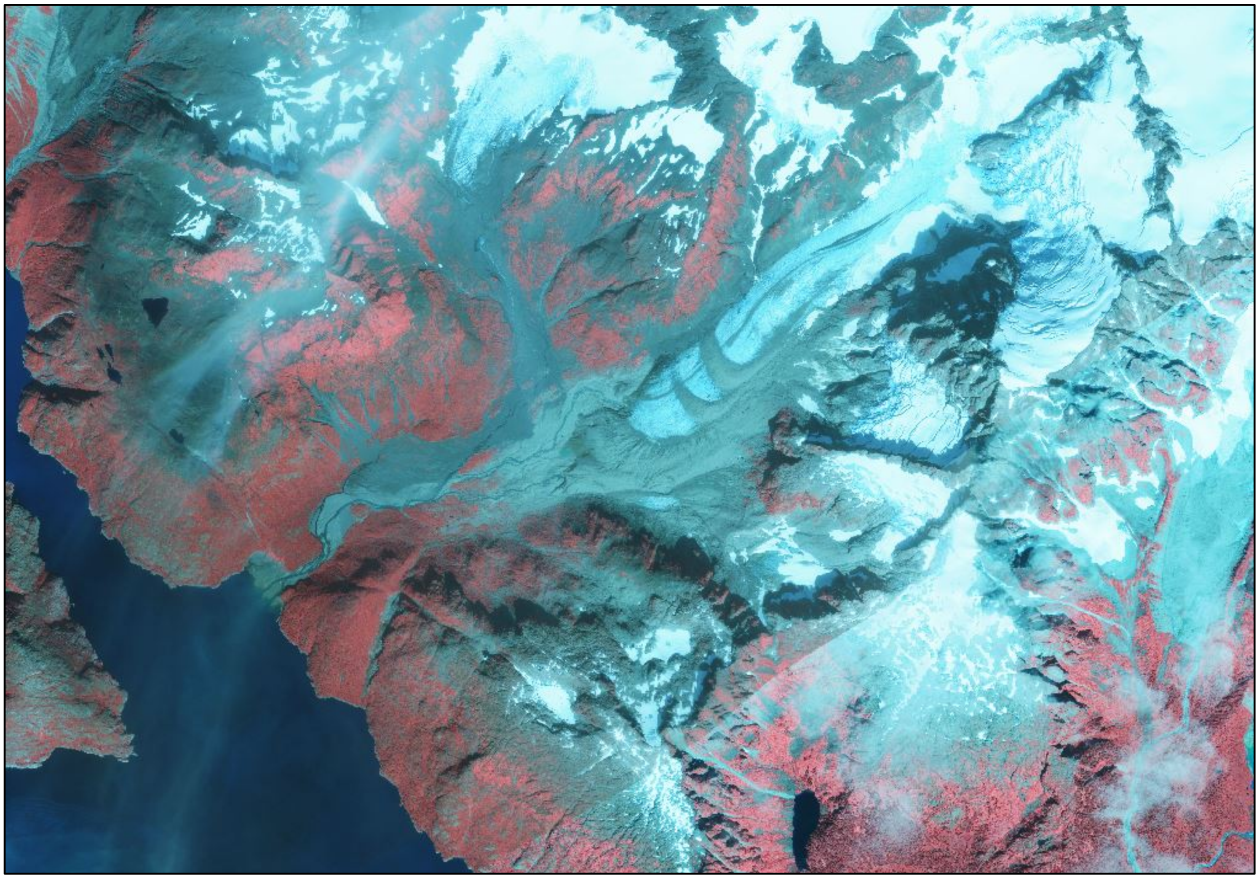

Figure 9. Example of Northeastern Glacier AOI, KEFJ, IKONOS CIR imagery 2005-2009.

Ecological and Regional Conditions

In the United States, the Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) work to define and map ecoregions for North America. Divided into hierarchal classification levels, ecoregions define similarities in geology, physiography, vegetation, climate, soils, land use, wildlife and hydrology, and are home to a number of wildlife and vegetation species. Extensive tracts of land with large wetlands, rivers and vegetation communities are common ecological environments throughout the state. There are twenty Level III ecoregions in greater Alaska; two of these ecoregions were found in areas mapped for this project. Caribou Lakes, Chinitna Bay, Lake Clark Pass, and Tuxedni Bay are all found within the Level III Ecoregion known as the Alaska Range.

The southernmost AOIs located in KEFJ were all located in the Pacific Coastal Mountains Level III Ecoregion. The following provides a summary of each Level III ecoregion found in the mapped areas for this project as provided by the EPA, (Gallant et *al*., 1995).

ALASKA RANGE LEVEL III ECOREGION: The Alaska Range Mountains of south central Alaska are very high and steep. This ecoregion is covered by rocky slopes, icefields, and glaciers. Much of the area is barren of vegetation. Dwarf scrub communities are common at higher elevations and on windswept sites where vegetation does exist. The Alaska Range has a continental climatic regime, but because of the extreme height of many of the ridges and peaks, annual precipitation at higher elevations is similar to that measured for some ecoregions having maritime climate.

PACIFIC COASTAL MOUNTAINS LEVEL III ECOREGION: The steep and rugged mountains along the southeastern and south central coast of Alaska receive more precipitation annually than either the Alaska Range (116) or Wrangell Mountains (118) Ecoregions. Glaciated during the Pleistocene, most of the ecoregion is still covered by glaciers and icefields. Most of the area is barren of vegetation, but where plants do occur; dwarf and low scrub communities dominate (**Figure 10**).

Figure 10. The Bear GLOF Source AOI (KEFJ) is located in the Pacific Coastal Mountain Level III Ecoregion. Photograph courtesy of Mr. Chuck Lindsay, NPS Alaska Region.

Methodology

Project Coordination

The project team consisted of personnel from both the National Park Service in Alaska and Saint Mary's University of Minnesota. Scope, intentions and goals for the project were established through phone conferences and numerous emails. Phone conferences and graphic consultations were held using Go-To Meeting software. A File Transfer Protocol (FTP) site managed by SMUMN GSS was used for data transfers.

Saint Mary's University of Minnesota provided project management and technical expertise in land cover delineation from aerial imagery as well as knowledge of geomorphic and anthropogenic characteristics required to identify changes over various time steps. As agreed at the outset of the project, land cover and vegetation mapping was classified using a combination of the National Land Cover Data (NLCD) system from the Multi Resolution Land Characteristics Consortium of the Environmental Protection Agency and the National Vegetation Classification Standard (NVCS) from the United States Geological Survey. Image analysis techniques and heads-up digital image interpretation were completed to create final datasets.

A preliminary scoping meeting was held on November 08, 2012 to finalize the project workflow process. Discussion items included:

- Identification of primary and secondary image sources to be used for mapping cover classes for the historic (1950s, 1980s) and current (2009) time periods;
- Identification and review of collateral datasets used to support and validate mapping;
- Identification/discussion of areas of interest locations for both LACL and KEFJ;
- Confirmation of classification systems including valid land cover and vegetation classification codes, potential subclasses and special modifiers.
- Finalization of additional descriptive features to be captured during interpretation such as classification of land cover change types (disturbance, successional), geomorphic changes influencing land cover, anthropogenic features, dominant vegetation cover types by species (where identifiable).

Following this meeting and using the information generated from discussions, SMUMN GSS proceeded with the mapping process.

Imagery

Imagery Acquisition

Digital imager***y was*** provided ***to*** SMUMN by the NPS for purposes of interpretation and completion of this project. The data provided included base imagery from the 1950s (1950-1957), the 1980s (1978-1985), the 2000s (2005-2009), and a range of collateral datasets. Careful review of each image type, from historical or current technology sources was completed to ensure quality control throughout the project. Additional SPOT5 imagery was downloaded from Alaska's Statewide Digital Mapping Initiative (SDMI). A complete index of imagery available for this project is located at the end of this report (**Appendix C)**.

Review of Image Processing

The use of aerial imagery for mapping purposes often requires several preprocessing steps. This project used images which already had been prepared for interpretation; some by SMUMN in recent years (Robertson, A. G., Knopf J. C., Johnson, D., Maffitt, B. L., 2014; Robertson, A., 2011). We are recounting the following information about image preprocessing for purposes of review and notating additional steps taken during this project.

<u>Scanning</u>

Scanning of the 1950's black and white photos and also the 1980's AHAP images used in this project was completed by the U.S. Geological Survey (USGS). Hardcopy aerial photographs were initially converted into un-georeferenced digital image files using a high resolution desktop scanner. Aerial photos were available in the USGS archives and digital scans were ordered through the USGS data store. SMUMN was responsible for identifying specific frames needed for this current project. Output images from the scanning process were provided to SMUMN in Tagged Image File Format (TIFF) and at various pixel resolutions. Scanning resolutions ranged from 15 to 21 microns (1200 dpi to 1800 dpi); some of the sub-project areas were scanned at multiple resolutions. The basic NPS specifications for the scanned photography used for this project included:

> *Scan resolution:* 21 microns (1200 dpi) or better. *Pixel Depth:* 8 bit
> *File Format:* TIFF. *Band Format:* Multi-band (red-green-blue-near infra-red) for color images and single band for black and white images.

<u>Georeferencing</u>

Once historic aerial photography has been scanned, the next step in the digital conversion process is the completion of georeferencing. Georeferencing or photogrammetric control is the process by which known ground control points are used to provide geographic reference for a scanned aerial image. The process involves choosing ground control points from a digital base map reference layer; identifying the same points on the scanned aerial photo; and then assigning the coordinate value for the control point on the base layer to the equivalent point on the scanned image. A minimum of 5 control points are typically required for basic georeferencing. For most of the scanned aerial photos used in this project, 15 or more control points had been applied to improve the accuracy of the georeferencing process. Since no photo identifiable GPS derived ground control points were available for use in the georeferencing process, all of the control points were registered from base imagery. The primary base image layer used for georeferencing images of each park was IKONOS, one meter resolution, four band, TIFF imagery.

Geographic registration of the 1950s and 1980s to the base image required additional control points due to the mountainous terrain and various flight-line altitudes that were used in these sets of photography. NPS worked cooperatively with SMUMN to identify and resolve problems associated with image processing. For each area, the optimum data source was selected based on availability, accuracy and resolution. The best georeferencing results were achieved using fully rectified IKONOS satellite imagery that had been provided to SMUMN by the NPS. Where this type of data was not available, lower accuracy LANDSAT panchromatic band, 15 meter resolution, was used. Unfortunately, the IKONOS satellite imagery was clipped tightly to the park boundaries. As a result, this data only provided a georeferencing solution for photos that were contained entirely within the park boundaries. As six of the seven AOIs were located near park perimeters, nearly all of the AOIs required supplementary base imagery as well as collateral DEMs. For photos that extended beyond these boundaries, lower accuracy base layers were used to supplement the IKONOS control points.

Orthorectification

Another step in the digital conversion process involves the orthorectification of georeferenced aerial images. This preprocessing step was completed on the imagery used for this project by SMUMN in previous years (Robertson, 2014 et *al.;* Robertson, 2011). Orthorectification is the process by which a digital elevation model (DEM) and camera calibration reports are used to correct image displacement caused by topographic variation and camera lens aberrations. This processing ensures that scanned images reside in both their correct topographic and geographic space. The primary input for the orthorectification process involved the use of a digital elevation model (DEM). A variety of DEM products were available, however, the primary elevation model used was the IKONOS DEM provided to SMUMN by the NPS. All IKONOS DEMs (30 meter resolution) were delivered to SMUMN in TIFF format. This DEM was created for the NPS by GeoEye with a vertical datum of WGS84/EGM96.

The IKONOS DEM provided by NPS was limited in its coverage to a tightly clipped boundary along the park edges. As a result, additional DEM products were required to orthorectify photos that fell partially or fully outside of the parks. These DEM's included NASA Shuttle Radar Topography Mission (SRTM) DEM data and also NASA ASTER DEM data produced by the U.S National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). The SRTM DEM with a vertical datum of WGS84/EGM96 geoid was a 30 meter resolution elevation product derived from data captured during an 11 day space shuttle mission in 1999. There was a limit to the northern extent of acquisition for this dataset since the northern latitude for the SRTM was 60 degrees. As a result, LACL was too far north in latitude to have SRTM-DEM coverage, however. KEFJ had almost complete coverage.

The ASTER DEM has a vertical datum of WGS84/EGM96 geoid was a 30 meter resolution elevation dataset available through the Alaska Statewide Digital Mapping Initiative (SDMI) website (http://www.alaskamapped.org/sdmi). Although some experts suggest that ASTER should be viewed as experimental because there may be particular issues that occur (i.e., mole runs, pits), this DEM does provide some value as a source for orthorectification. The ASTER DEM provided coverage needed for both parks and did not have the data holes encountered with the SRTM DEM. The ASTER DEM and the IKONOS DEM were merged together with the priority elevation data coming from the IKONOS DEM.

Potential differences may occur in the orthorectified imagery at the transition between the IKONOS DEM and the ASTER DEM or the SRTM DEM. In addition, some data may be clipped or erased from the orthorectified image in the DEM's "no data" area. In order to alleviate these issues SMUMN created a composite DEM mosaic using SRTM and ASTER elevation data overlaid by IKONOS DEM for this project. All of the calculations and processes used to create the composite DEM were executed in ArcGIS 10 using the Spatial Analyst extension. ASTER DEM tiles were downloaded and mosaiced into one large DEM ensuring sufficient coverage beyond park boundaries. This composite ASTER DEM was then mosaiced with the IKONOS DEM with particular attention to ensure that the ASTER had lesser priority. As a final step, the multi DEM composite was converted to TIFF format, projected to Alaska Albers Equal Area Conic and then converted into a DEM format for use in the orthorectification software.

The composite DEM product provided an elevation model that incorporated the entire area of scanned photo coverage for the project. This enabled the utilization of the IKONOS for interior images and a combination of IKONOS and ASTER or SRTM data for images that extended beyond park boundaries. As a result, all available images were orthorectified using the best available although the primary DEM was the IKONOS DEM provided to SMUMN by the NPS. In other words, if IKONOS DEM values were present, they were used first. The composite DEM data was only used to fill "no data" areas or to extend the outer edges of the DEM mosaic beyond Park boundaries. The final dataset assumed the vertical datum of the IKONOS DEM.

Camera calibration reports provide important input to the orthorectification process. These reports, created by the United States Geological Survey (USGS), contained camera parameters that were used by the orthorectification software to better account for camera distortion and lens aberrations during image processing. These reports were specific to the camera used for each photo acquisition mission and typically contained distortion correction information such as focal length, principle point of symmetry, and X/Y coordinates for the photo fiducial marks. For this project, complete (useable) camera calibration reports for the images used in this project were not available for all project areas. For example, none of the reports covering the 1950's era photography in LACL provided sufficient data for the orthorectification process (i.e. no fiducial marks and limited lens information).

The software package used for orthorectification of images used in this project was OrthoMapper ver. 5.6.7 from Image Processing Software Inc. OrthoMapper has been effective for processing large amounts of data (e.g. hundreds of scanned aerial photos) and provides a more appropriate environment for production work flows than other software packages. With OrthoMapper, individual project folders were created for each photo. This allowed the camera calibration information to be initially entered so that the camera report file generated could be used for every photo associated with it. In other software available, camera report information needs to be entered for each photo.

Mosaicing

Mosaicing is the joining of adjacent imagery to create a seamless digital image. Individual photos or satellite scenes are captured at different times, different days, or during different years. This may result in image variances which must be adjusted to create a photo mosaic of the entire area under study. Photo mosaicing typically involves several steps, reviewed briefly below:

- Selection of input photos based on image quality, color, tone, texture, histogram variation and overlap;
- External color and tone balancing by visually matching adjacent images so that not as much adjustment is required;
- Clipping the best portions of individual photos before mosaicing by following natural features (valleys, ridges, streams, roads etc.) in order to mask seams, and with focus on the center of the photo to minimize distortion from radial displacement;
- Software mosaicing and color balancing with image stretching and manipulation; and,

The IKONOS imagery used in this project was available in mosaic format; all of the AHAP and black and white photos were not. SMUMN completed initial steps to mosaic some of the 1950s black and white photos as well as the 1980s AHAP photos but determined that the use of individual photos provided the best option for completion of delineation and classification of land cover for the particular AOIs in this project (**Figure 11**).

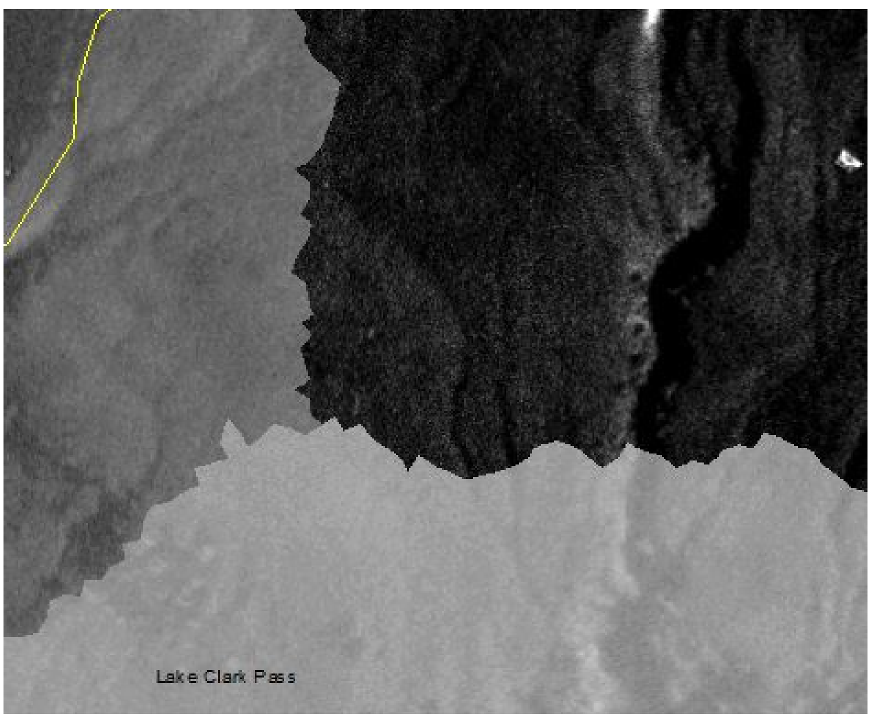

Figure 11. Example of mosaiced black and white photographs taken of Lake Clark Pass in the 1950s. Individual photos provided the best option for this project.

Project Imagery

<u>1950s Black & White Imagery Review</u>

This project data set contained digital aerial photo imagery taken of LACL and KEFJ (**Figure 12**). The imagery was procured from air photo flying missions conducted by the U.S. Air Force, USFWS and others from 1952 through 1955 and 1957 according to USGS EarthExplorer. The photo emulsion was black and white; the scale of the final hardcopy photo print products was 1:40,000.

Figure 12. Lake Clark Pass, B/W, photograph taken 8/21/1954.

1980s – Alaska High Altitude Program (AHAP) Imagery Review

This project dataset contained digital aerial photo imagery of LACL and KEFJ (**Figure 13**). The imagery was procured from air photo flying missions conducted by the NASA Ames Research Center in 1978 and 1980. The photo emulsion was color infra-red and the scale of the final hardcopy photo print products was +/- 1:63,000.

Figure 13. AHAP photo captured 8/25/1978, Lake Clark Pass in LACL.

2000s IKONOS Imagery Review

GeoEye IKONOS is a commercial earth observation satellite launched in 1999 and the first satellite to offer publicly accessible high resolution imagery for mapping purposes. IKONOS images are made available in one meter resolution panchromatic and four meter resolution multispectral bands. Over a period of 2005 to 2010, the NPS purchased IKONOS imagery coverage for several national parks in Alaska. This multispectral IKONOS satellite imagery was pan-sharpened to one meter resolution and processed to 16 bit pixel depth (**Figure 14**).

The IKONOS data included a 30 meter resolution, single band, 16 bit pixel depth digital elevation model. IKONOS imagery was available for all seven AOIs for this project. Localized areas of the IKONOS imagery were difficult to interpret for various reasons such as cloud cover and shadow. The image analyst then sought out appropriate SPOT5 imagery to complete mapping and classification efforts. This provided an option for completing mapping for areas that might otherwise have been left incomplete. These issues are discussed further in the Results section of this report.

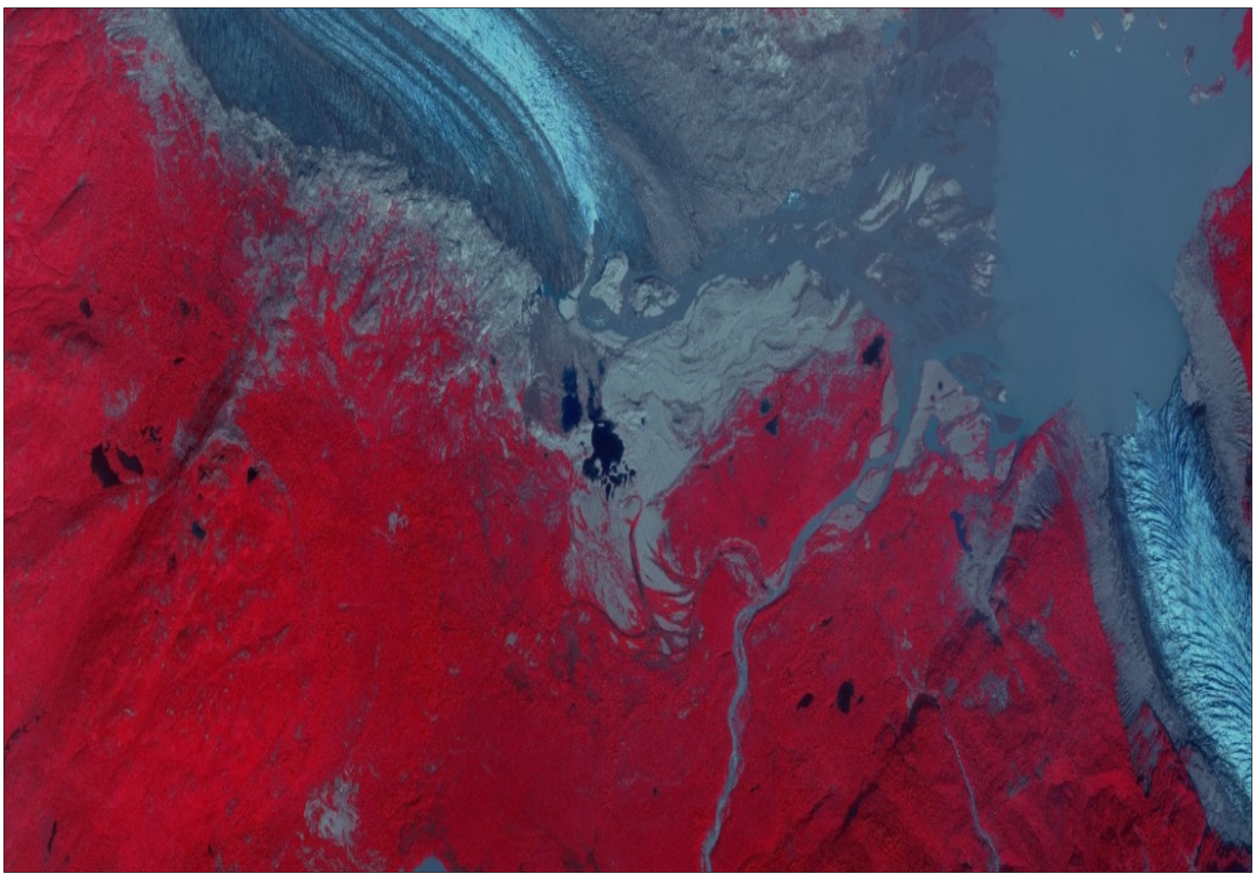

Figure 14. IKONOS imagery acquired circa 2008.

SPOT5 Imagery Review

The acquisition and processing of SPOT5 imagery is currently underway as part of the Statewide Digital Mapping Initiative (SDMI) for Alaska. Source imagery was gathered by Spot Image Inc. and processed by Fugro Earthdata and Aerometric Inc. into multi-band, orthorectified, mosaiced and color balanced image tiles.

SDMI acquisition of source SPOT data started in 2009 and is scheduled for completion by 2016. SPOT5 is the fifth generation of SPOT (Système Pour l'Observation de la Terre) satellites. The satellite was launched May 3, 2002 from Guiana Space Center, French Guyana. The SPOT5 platform has an oblique viewing capability with an adjustable angle of +/- 27 degrees (**Figure 15**).

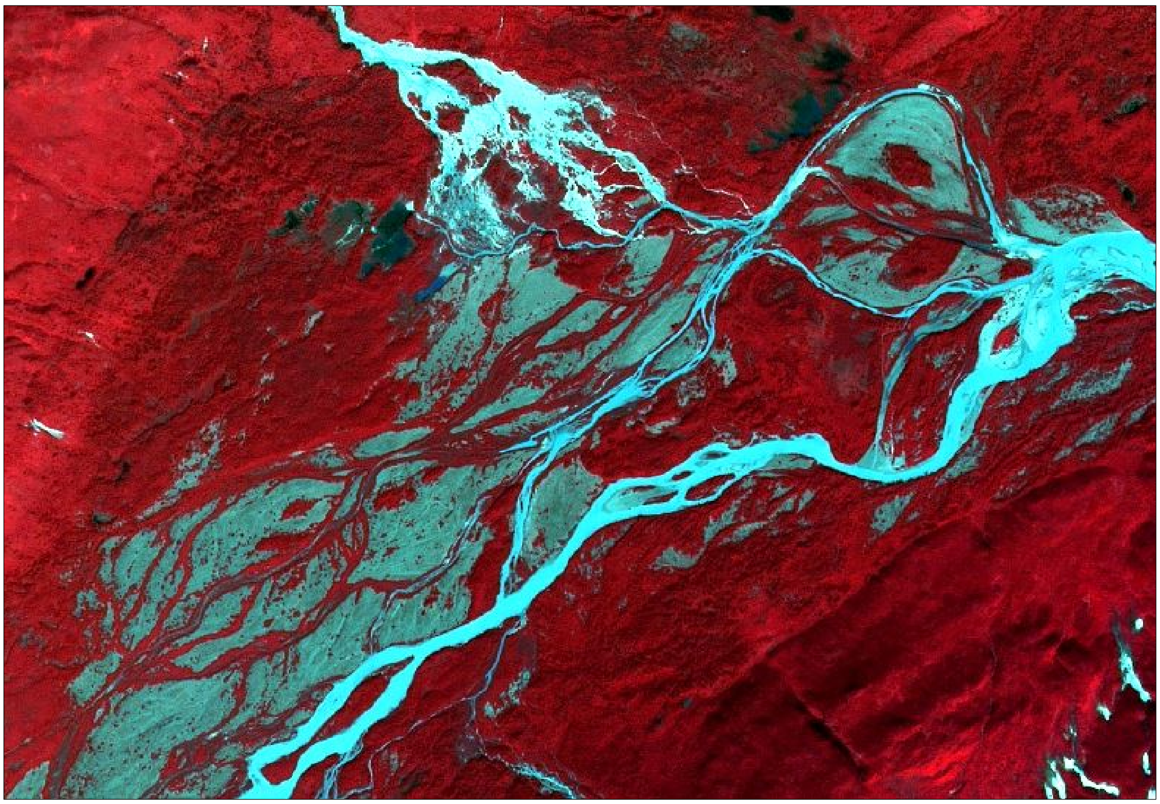

Figure 15. SPOT5 CIR imagery captured 8/25/1978. This area is located east of the photos in Figures 11 through13; located in Lake Clark Pass and LACL.

Improvements over earlier SPOT satellite platforms include multiple image types with 10, 5 and 2.5 meter resolution and a wider acquisition swath width. SPOT5 also has a high resolution stereoscopic (HRS) stereo viewing instrument which allows for simultaneous acquisition of stereo pairs. SPOT5 sensors gather spectral bands in the panchromatic and multispectral (green, red, near-infrared, short-wave infrared) spectrum.

In the future, SPOT5 imagery will be available for the entire extent of Alaska through the ongoing efforts of the SDMI acquisition program. Pilot projects already completed in other parts of the state have demonstrated that SPOT5 imagery is of suitable resolution and emulsion for wetland mapping to standards established by the FGDC.

As noted earlier, certain areas within each of the LACL and KEFJ AOIs included IKONOS (2006-2009) imagery that was obscured by shadowing or cloud cover which then prevented positive identification on the land surface features. The incorporation of SPOT5 imagery as a primary and collateral dataset was used in this project when the primary IKONOS imagery was obscured. In these instances SPOT5 was used only to support IKONOS –based decisions. Since the acquisition date of the SPOT5 imagery was within one or two years of the IKONOS imagery, it allowed for comparable feature identification and delineation. The SPOT5 imagery included CIR, 2.5 meter resolution, and was used to reduce or eliminate areas that might otherwise be coded 999 (unattributable). The effectiveness of using SPOT5 to supplement IKONOS imagery is discussed further in the Results section of this report.

Collateral Datasets

Collateral datasets included spatial data layers provided by the NPS or acquired by SMUMN in order to assist in the image analysis process. Collateral information from several spatial databases contributed to an understanding of the ecological and anthropogenic conditions of the project study area. While not created primarily for land cover mapping purposes, various datasets provided additional information that was used to support land cover interpretation and change classification decisions during the mapping process. The following is a summary of datasets which were used for the study area:

- IKONOS Imagery: 2005 – 2009, 1 meter, color-infrared, TIFF format;
- 1980's Imagery: Alaska High Altitude Aerial Photography (AHAP), 1984 – 1986, one-meter, color-infrared, TIFF format. These hard copy photos were taken at +/- 1:65,000 and scanned at 17 – 25 microns;
- 1950's Black and White Imagery: 1954 – 1956, one-meter, orthophotos. These hard copy photos were taken at +/- 1:40,000 and scanned at approximately 15 microns;
- 19 areas of interest (AOI), totaling 123,000 acres, spread across LACL and KEFJ in shapefile format. These datasets provided additional regional information;
- DEMs derived by GeoEye as part of the IKONOS imagery orthorectification process;
- 1998 SPOT: classified land cover map from Pacific Meridian Resources for LACL;
- 1999 Landsat: classified land cover map from the Bureau of Land Management and Ducks Unlimited Inc. for KEFJ;
- 2008 photo-interpreted land cover map from Alaska Natural Heritage Program for KEFJ;
- Other: National Wetland Inventory, STATSGO, National Hydrography Dataset;
- Other: NPS specific spatial data layers including administrative boundaries for both KEFJ and LACL;
- Other: oblique aerial images, ground level photographs, vegetation transects, and plot summaries downloaded from the NPS theme manager. The image analysts working on this interpretation project did not have the opportunity to visit the project area in order to review and address types of land cover, conditions or geomorphic processes. As a result oblique aerial images and ground level photos provided an additional source of information for classifying landcover and change types.

Development of Photointerpretation Conventions

For many years, the primary method of developing cost effective mapping over large geographic areas has been the interpretation of remotely sensed imagery. Image interpretation is defined as the science and art of analyzing terrain features as recorded on aerial or spaced based imagery and, through deductive reasoning, developing thematic mapping based on those characteristics. Image interpretation techniques are based on three fundamental assumptions:

- Remotely sensed imagery is a record of the longtime natural and man-made processes which are reflected on the image as surface features;
- The surface features on an image can be grouped together to form patterns that are characteristic of particular environmental conditions;
- The environmental conditions and their reflected patterns are repetitive; that is, similar environments will produce similar image patterns while different environments will usually produce different image patterns.

The terrain elements that collectively produce patterns on remotely sensed imagery include topography (surface geometry), vegetation, regional drainage, local erosion, and anthropogenic features. All of these elements are essentially interrelated; however, they may also be separated during the interpretation process to facilitate analysis, description, evaluation and classification of thematic features (such as wetlands) that are visible on an image.

Interpretation of remotely sensed imagery is a subjective process. Before attempting to interpret terrain characteristics and thematic features, the interpreter must understand the properties inherent in the images themselves (emulsion, tone, texture, signature, and scale). In addition, because image characteristics relate most strongly to physical science, the interpreter must have an understanding of the basic concepts of climatology, geomorphology, geology, ecology, and hydrology.

Deductive reasoning, based on the physical characteristics of the imagery being assessed and the scientific characteristics of the terrain elements that are represented on the image, allows a skilled interpreter to develop and map thematic information from remote sensing. For purposes of consistency a primary interpreter was assigned to complete all of the feature delineations and classifications. The interpreter and supporting analysts from SMUMN have significant experience in mapping projects in Alaska. Team members from both SMUMN and the NPS also completed progressive reviews, via conference calls, when interpretation calls needed further input from regional experts. The quality control process also included the consistent use of the hybridized classification system (**Appendix A**).

National Land Cover Dataset Hybridization

The classification hierarchy selected for this project was based on the National Land Cover Dataset (NLCD) model developed by the Multi Resolution Land Characteristics Consortium of the Environmental Protection Agency and the National Vegetation Classification Standard (NVCS) from the United States Geological Survey (**Appendix A**).

The NLCD dataset is a nationwide Landsat-based, 30 meter resolution database which provides spatial references and descriptive characteristics of the land surface including thematic mapping. This dataset includes a standardized coding scheme noting the distinction between various features such as hydrology, forests or agricultural areas. The classification was created by the Multi Resolution Land Characteristics (MRLC) Consortium.

Although the NLCD is a comprehensive schema for descriptive characteristics of the land surface, it was originally designed for a national land cover audience. There was some concern that unique land characteristics within LACL and KEFJ were not adequately described in the NLCD. For this reason the project team determined a need for the creation of additional attributes which might enhance the standardized NLCD model. This work was done to increase the understanding of unique land cover characteristics found in portions of specific project areas. For example the NPS wanted an attribute which would describe beaver activity. *Empetrum sp.*, a dwarf evergreen shrub (**Figure 16**) was also classified. In addition, a code was created to record lichen communities, especially for the Caribou Lakes AOI. All new additions to the classification model were fully discussed and vetted by SMUMN team members and staff from the NPS before inclusion. As the project progressed, the need to add new attribute fields to the existing schema was adjusted as necessary. This was done when a particular change code did not accurately explain the vegetation or geomorphic processes in all situations.

Figure 16. *Empetrum nigrum.* The NLCD was hybridized to accommodate unique features.

The following land cover attribute codes were added to the NLCD model:

- 53- Multi-level canopy, shrub dominant: Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions;
- 54-Multi-level canopy, coniferous tree dominant: Areas dominated by coniferous trees generally greater than 5 meters tall, and 60% to 100% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage. This class is characterized by an under story vegetation cover visible through the tree canopy;
- 55-Multi-level canopy, deciduous tree dominant: Areas dominated by deciduous trees generally greater than 5 meters tall, and 60% to 100%of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change. This class is characterized by an under story vegetation cover visible through the tree canopy;

The following change attribute codes (identifying changes between the three time steps) were also added to the hybridized NLCD model;

- 10-Vegetation establishment; reserve this for situations in which land cover changes from barren to vegetation establishment;
- 25-Vegetation development/expansion intertidal area;
- 27-Aquatic bed formation/expansion in palustrine area; reserve this for conditions in which land cover changes from open water to aquatic bed in palustrine areas;
- 28-Open water formation/marine intrusion;
- 29-Beaver activity; reserve this for pond formation in which dam formation/ponding occurs;
- 73-Lichen-found in a variety of forms, harsh environments such as mountaintops or Polar Regions;
- 76-Lichen/shrub sparse upland; dominated by shrubs with lichens typically greater than 30% of total vegetation. Characteristic of shrub intrusion in otherwise lichen dominated areas;
- 90-Tide position differences between images;
- 999-shadows/mosaic/image shift/image smear; identify these issues in the “comments” field of the attribution table.

The NCLD classification used in this project captured nearly all of the special references and descriptive characteristics of the land surface. On occasion, the land cover and available sub-codes did not accurately describe the characteristics of the feature or the geomorphic change noted by the image analyst. New land cover codes and also change codes were developed, as necessary, and then added to the NCLD hierarchical classification schema in the geodatabase as necessary. The development of these codes was an iterative effort and required collaboration between NPS and SMUMN (**Figure 17**).

Table

AialikBayRS

OBJECTID *	SHAPE *	LandCove	LC_Code	Sub_LC_code	LC_code_80	LC_subcode_80	LC_code_00	LC_subcode_00	ChgCode50_80	ChgCode80_00
288	Polygon	<Null>	75	8	75	8	75	8	<Null>	<Null>
289	Polygon	<Null>	30	8	13	<Null>	30	8	30	31
290	Polygon	<Null>	30	8	30	8	75	8	<Null>	10
293	Polygon	<Null>	30	8	30	8	999	<Null>	<Null>	<Null>
294	Polygon	<Null>	75	8	75	8	999	<Null>	<Null>	999
295	Polygon	<Null>	30	8	999	<Null>	30	8	999	999
296	Polygon	<Null>	13	<Null>	30	8	30	8	31	<Null>
297	Polygon	<Null>	13	<Null>	999	<Null>	999	<Null>	999	<Null>
298	Polygon	<Null>	13	<Null>	30	8	30	8	31	<Null>
299	Polygon	<Null>	30	8	75	8	75	8	10	<Null>
301	Polygon	<Null>	12	<Null>	12	<Null>	12	<Null>	<Null>	<Null>
304	Polygon	<Null>	30	8	75	8	75	8	10	<Null>
305	Polygon	<Null>	30	8	13	<Null>	30	8	30	31
311	Polygon	<Null>	71	<Null>	71	<Null>	71	<Null>	<Null>	<Null>
315	Polygon	<Null>	50	<Null>	30	8	50	<Null>	6	10
316	Polygon	<Null>	75	8	75	8	999	<Null>	<Null>	<Null>
320	Polygon	<Null>	50	<Null>	50	<Null>	52	<Null>	<Null>	5
321	Polygon	<Null>	50	<Null>	30	8	52	<Null>	6	5
324	Polygon	<Null>	50	<Null>	50	<Null>	999	<Null>	<Null>	<Null>
335	Polygon	<Null>	75	8	75	8	999	<Null>	<Null>	999
337	Polygon	<Null>	30	8	30	8	50	<Null>	<Null>	10
349	Polygon	<Null>	75	8	50	<Null>	50	<Null>	5	<Null>
367	Polygon	<Null>	42	<Null>	999	<Null>	999	<Null>	999	<Null>
368	Polygon	<Null>	30	11	52	<Null>	42	<Null>	12	2
369	Polygon	<Null>	30	11	999	<Null>	999	<Null>	999	999
371	Polygon	<Null>	44	<Null>	41	<Null>	41	<Null>	40	<Null>
372	Polygon	<Null>	52	<Null>	999	<Null>	52	<Null>	999	999
375	Polygon	<Null>	52	<Null>	45	<Null>	45	<Null>	2	<Null>
383	Polygon	<Null>	75	8	75	8	75	8	<Null>	<Null>
389	Polygon	<Null>	13	<Null>	999	<Null>	13	<Null>	999	999
390	Polygon	<Null>	13	<Null>	999	<Null>	13	<Null>	999	999
397	Polygon	<Null>	50	<Null>	52	<Null>	52	<Null>	5	<Null>
398	Polygon	<Null>	50	<Null>	52	<Null>	11	7	5	14
399	Polygon	<Null>	50	<Null>	52	<Null>	11	7	5	14
400	Polygon	<Null>	30	1	32	1	11	7	<Null>	14

Figure 17. The screen shot example above includes a small selection of data housed in the geodatabase attribute table for the Aialik Bay Ranger Station AOI, KEFJ.

As noted, a hybridized NLCD was developed to address unique areas for the project. The example includes a partial list (**Figure 18**) of land cover codes and characteristics.

List of NLCD land cover types			
NLCD_code	NLCD_desc	Sub_LC_Code	SCode_desc
10	Water	1	high gradient stream
		2	braided river
11	Open Water	2	river
		3	rill
		4	intertidal
		5	river cutting through estuary
		6	lake
		7	pond
12	Pernnial Ice/Snow		
13	Annual Snow		
30	Barren		
		2	braided river
		8	mountain slope or talus
		9	wash
		10	rock
		11	high gradient stream
31	Barren Land		
32	Unconsolidated Shore		
		1	sand/gravel
		2	braided river
		3	mud flats
		4	intertidal
		5	river cutting through estuary
40	Forested Upland		
41	Decidous Forest		
42	Evergreen Forest		
43	Mixed Forest		
44	Deciduous Woodland		
45	Evergreen Woodland		
46	Mixed Woodland		
47	Decidous Sparse Woodland		
48	Evergreen Sparse Woodland		
49	Mixed Sparse Woodland		
50	Shrubland	2	braided river
51	Dwarf Shrub		
52	Shrub/Scrub		
53	Multi-level canopy, shrub dominant		
54	Multi-level canopy,coniferous tree dominant		
55	Muti-level canopy, deciduous tree dominant		
70	Herbaceous Upland		
71	Grassland/Herbaceous		
72	Sedge/Hebaceous		
73	Lichens		

Figure 18. Example of hybridized NLCD codes for the project. The complete list of hybridized codes, sub codes, descriptions and comments are found in in the appendix (**Appendix A**).

Change codes were also formatted as a key for reference and validation (**Figure 19**).

	Change Codes (e.g., ChgCode50_80)
No.	**Decription**
	Vegetation Changes
1	Spruce closure
2	Spruce establishment/expansion
3	Spruce dieback/stand opening
4	Shrub closure
5	Shrub establishment
6	Shrub loss
7	Hardwood forest closure
8	Hardwood forest establishment
9	Hardwood forest dieback/stand opening
10	Vegetation establishment
27	Aquatic bed formation/expansion in palustrine area
28	Open water formation/marine intrusion
29	Beaver activity
	Geomorphic Changes
11	Channel formation
12	Channel abandonment
13	Pond drying
14	Pond/Lake Formation
15	Wetland loss
16	Wetland creation
17	Mass wasting
18	Coastal subsidence/flooding
19	Coastal uplift
20	Ash deposit
21	Alluvial deposit
22	Colluvial deposit
26	Ice loss/glacial retreat
35	Lake Drainage
	Intertidal
23	rill formation
24	rill abandonment
25	vegetation development/expansion in intertidal area
30	annual snow increase

Figure 19. Screen shot example of hybridized change codes for the project. The list of codes for vegetation, geomorphic and intertidal changes are also found in the appendix (**Appendix B**). .

Geodatabase Assembly

SMUMN assembled ESRI ArcGIS version 10.2 file geodatabases using a projection in Alaska Albers and referenced to the NAD83 geodetic datum. These geodatabases contained the AOI boundaries, fully attributed land cover polygon layers, and topology verification rules for both LACL and KEFJ. They also included data for all three time periods for this project: 1954 - 1956, 1984 - 1986, and 2005 - 2009.

Due to the customization of the NCLD, a modified attribute table was created within the geodatabase for each AOI. Attribute fields in each geodatabase held data derived from various imagery interpretations for each time step. These interpretations resulted in both vegetation and geomorphic change codes.

After all delineations were completed and the appropriate classification codes were assigned, the "dissolve" geoprocessing tool was utilized from the ArcMap Toolbox. Dissolved polygons for each time step were selected and the LC_Code fields within the attribute table were exploded to eliminate multi-part features for each of the years: 1950s, 1980s, and 2000s.

Landcover Mapping and Classification

Landcover mapping and classification was completed using heads-up digitizing and ArcMap v10.2 editing tools with the primary imagery and other collateral datasets as a backdrop for reference. This work was completed by image analysts for three different time periods: 1950s (B/W), 1980s (AHAP), and, 2000s (IKONOS). SMUMN consistently applied minimum mapping units (MMU) and scales for interpretation and delineation. This was an important process to enhance quality assurance throughout the project.

The 1950s era delineation was made at a maximum zoom scale of 1:15,000 with a minimum mapping unit of five acres. The minimum mapping unit for the 1980s data was three acres as digitized at a maximum zoom scale of 1:10,000. And finally, the minimum mapping unit for the 2005-2009 IKONOS imagery was one acre; digitized at a maximum zoom scale of 1:5,000. It is important to note that on the circa 1950s and 1980s imagery delineations were also performed at a zoom scale of 1:5,000.

Land cover interpretation and attribute assignment was completed using the hybridized land cover NLCD system for each of the three time step imagery sources: 1950s, 1980s, and 2000s. Each imagery source required careful review and analysis.

A brief description along with a sample of each of the three primary imagery sources follows. Special considerations that were taken by the image analyst are also discussed in the following pages.

Landcover Mapping and Classification - 1950s B/W Imagery

This mapping was completed first by cutting individual land cover and vegetation polygons from a master polygon (single AOI polygon). Delineation was then completed using a maximum zoom scale of 1:15,000 and a minimum mapping unit of five acres (**Figure 20**). A classification attribute was determined then recorded in the attribute table for each of the delineated polygons.

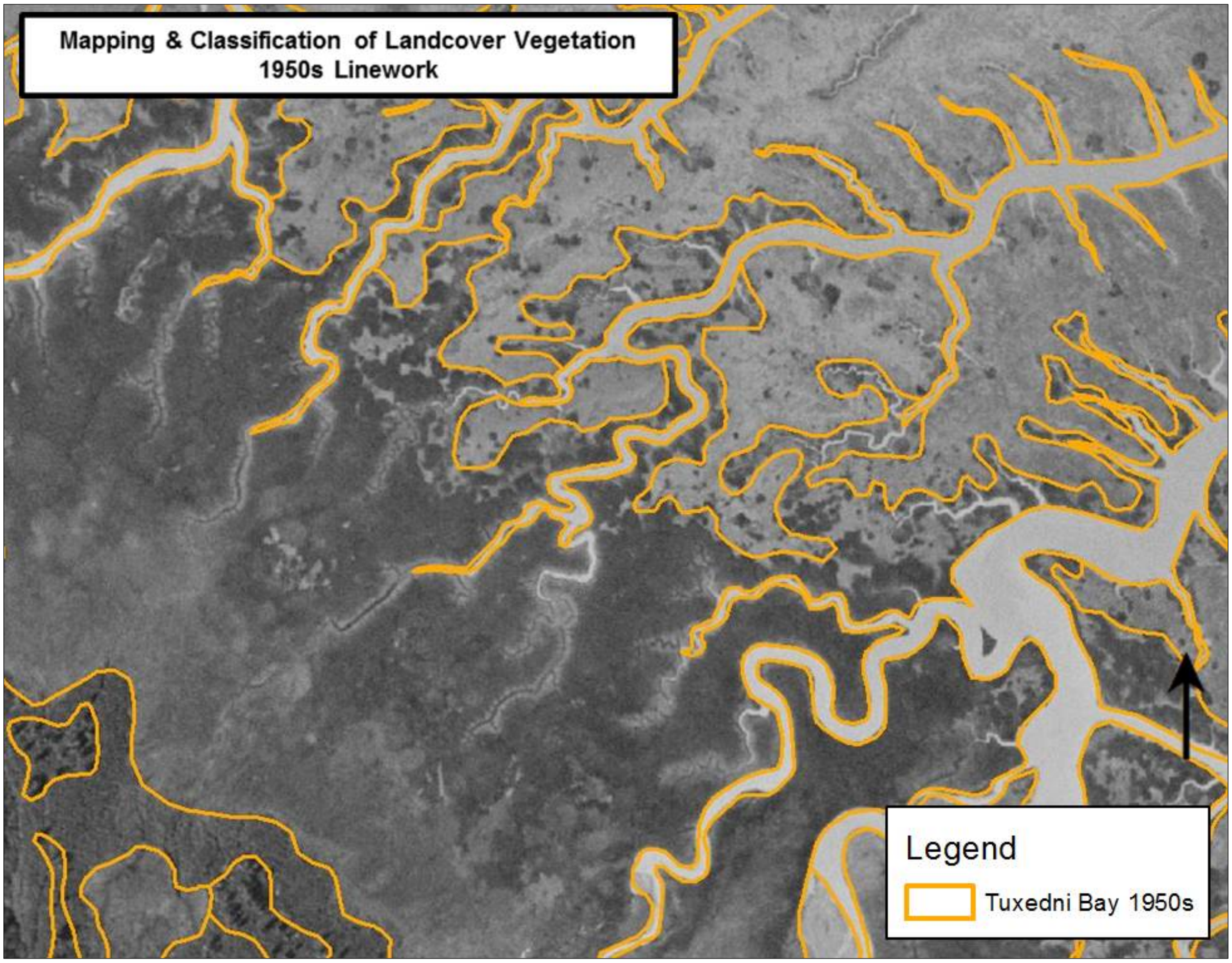

Figure 20. Sample of linework, Tuxedni Bay, LACL; B/W photo, 8/2/1954.

Landcover Mapping and Classification - 1980s AHAP Imagery

This imagery was captured in the 1980s. The image interpreter first analyzed and carefully compared features to those seen in the 1950s delineation. The 1980s layer was created by sub dividing (parsing) land cover, vegetation and geomorphic changes as identified from the 1950s polygons (**Figure 21**). Delineation was completed using a maximum zoom scale of 1:10,000 and a minimum mapping unit of five acres.

Vegetation and geomorphic change attributes were then recorded in separate 1980s attribute fields of the geodatabase. The attribute table was edited so that fields were populated with land cover classifications (for both the 1950s and 1980s imagery) as well as fields identifying specific vegetation or geomorphic changes. For example, vegetation change codes noted vegetation closings, openings or new vegetation establishment as identified by the image analyst.

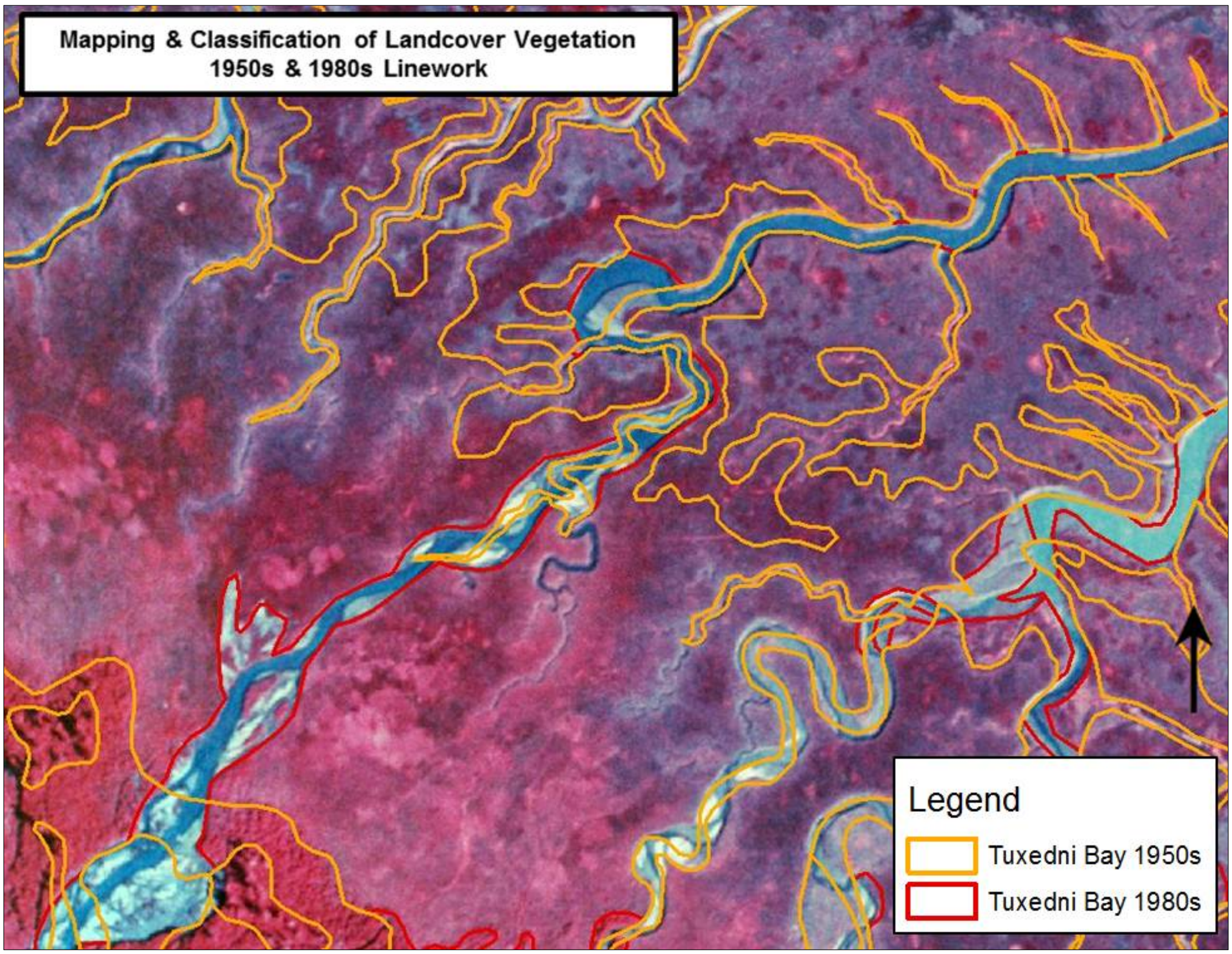

Figure 21. Sample of linework Tuxedni Bay, LACL; August 26, 1978 AHAP image.

Landcover Mapping and Classification - 2000s IKONOS Imagery

The final delineation and classification for the project was completed using IKONOS imagery (**Figure 22**). Delineation was completed using a maximum zoom scale of 1:5,000 and a minimum mapping unit of five acres. The same methodology steps used during the 1950s and 1980s mapping and classification of the project were applied to the IKONOS imagery. This included the cutting of land cover polygons to represent vegetative and geomorphic changes.

Descriptive attributes describing dominant vegetation cover or other discernible characteristics were classified. These attributes were then recorded in separate fields of the collective attribute table which also contained the original data from the 1950s and the 1980s. Data was then complete for all three time periods: 1950s, 1980s, and the 2000s.

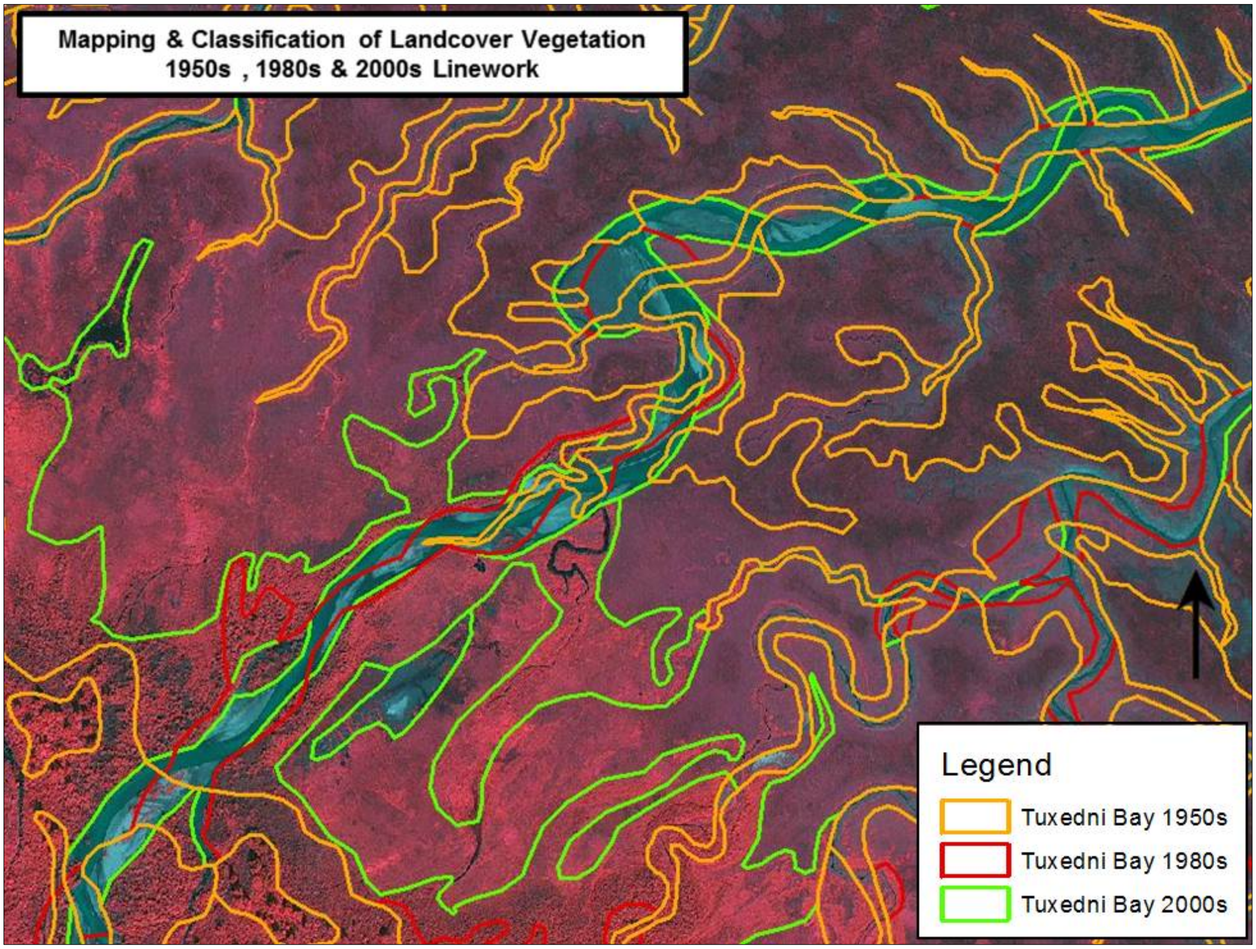

Figure 22. Sample of linework of Tuxedni Bay, LACL; CIR IKONOS imagery from 2006-2010.

Landcover Mapping & Classification –SPOT5 Imagery

Thousands of landcover features were delineated and classified for this project. At times, particular issues in analyzing the imagery occurred. One example was heavy shadowing seen in small portions of the IKONOS imagery (**Figure 23**).

In instances where a classification could not be assigned using the IKONOS imagery (due to cloud occlusion, shadowing, smearing, mosaicing) a "999" code was initially recorded for the feature in the attribute table. The image analyst was then able to consult 2010 SPOT5 imagery so that undetermined features viewed in the IKONOS imagery were mapped and classified using this alternative imagery. The outcome of using alternative imagery in this special circumstance is discussed in the results section of this report.

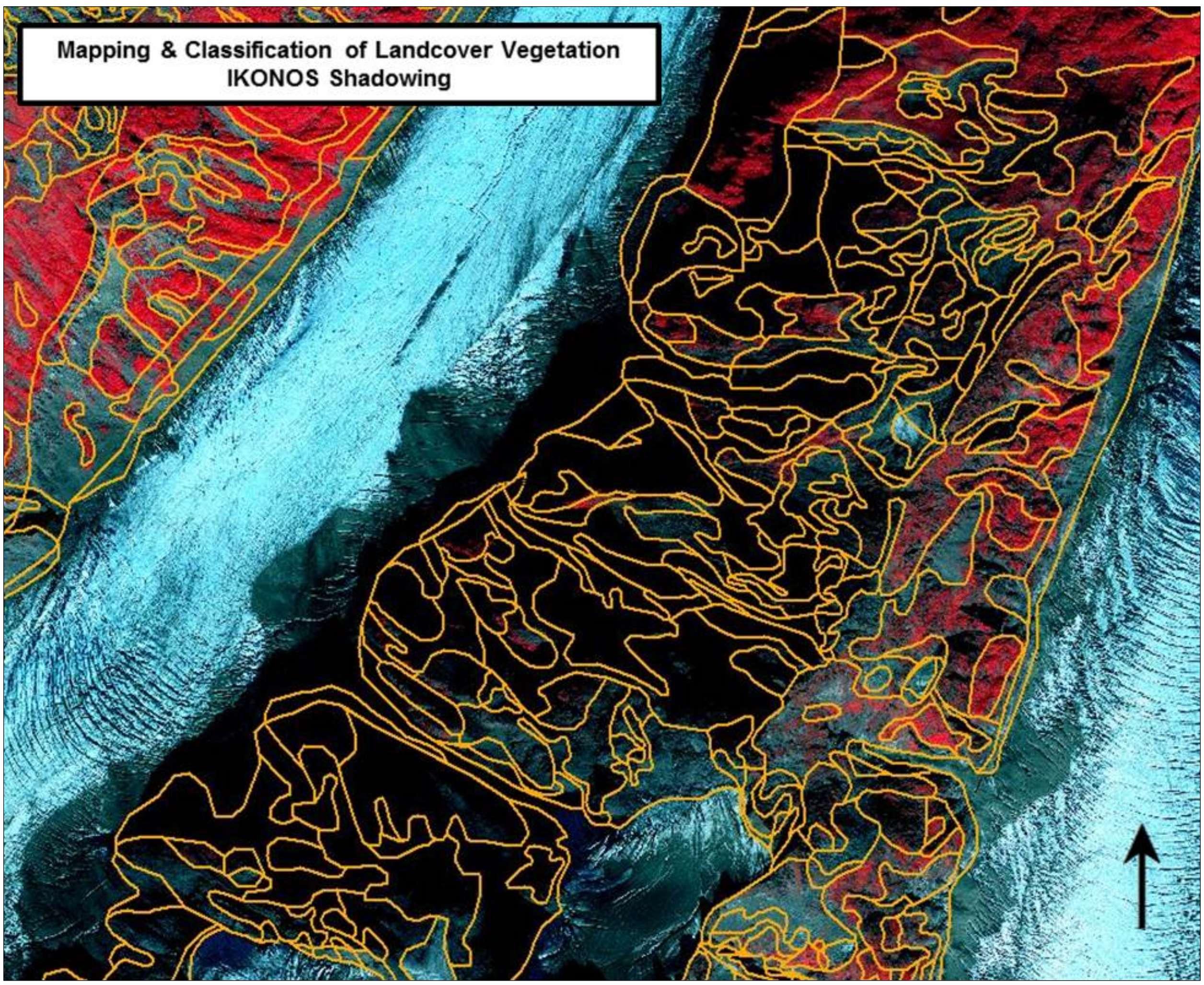

Figure 23. Sample of shadowing as seen in the IKONOS imagery (black area). In this instance a "999" code for landcover features was entered into the attribute table.

Quality Assurance

Quality control to create the final product for this project was managed by consistently applying the methodology described above. The image interpreter completed the project onscreen using a hybridized classification system and using their best professional judgment. The geodatabase creation was kept standard for each AOI by establishing a table schema which was imported to all AOI's prior to delineation and classification work.

Compliance to the delineation scale allowed for a level of consistency with interpretation calls across the images. Image enhancements were kept standard for each image dataset. For example, symbology for the IKONOS images for each AOI used a false color composite and an image stretch of two standard deviations. Delineation also conformed to a minimum mapping unit of two acres for feature delineation. An exception was open water features, where if these were visible at the delineation scale they were delineated.

All delineation started with the earliest time step (1950's) and the attribution of cover types was completed before the process proceeded to other time steps sequentially. Geometry was preserved as each previous time step was carried over to the next for delineation. Periodic reviews were conducted throughout the project (both internally and by NPS specialists) to address questions and to maintain consistency.

Other quality control checks were applied consistently throughout the project for each of the seven AOIs. These quality control procedures included:

- A check for "nulls" was performed for each of the land cover codes in the 1950s, 1980s, and the 2000s fields within the table to insure completeness;
- A cross-check of all attribute fields was performed to identify erroneous coding issues;
- A sort of the "Shape Area" column within the schema was performed to identify and repair any "sliver" or "ghost" polygons;
- Topology was run on all line work with specified rules such as features must not overlap or gaps;
- The final, seamless land cover geodatabase was designed to meet all requirements of the NPS spatial data guidelines.

Results

Deliverables

Geodatabase

SMUMN assembled ESRI ArcGIS version 10.2 file geodatabases using a projection in Alaska Albers and referenced to the NAD83 geodetic datum. A functional schema was developed and utilized by the mapping team for entering critical data into unique attribute fields revealing land cover and change codes for each of the time steps. The geodatabases were developed for this project based on input during scoping meetings and refinements to all efforts as the work progressed.

The project geodatabases included interpreted land cover classes for all mapped time periods. For example, the 1950 era file geodatabase included only land cover classified from the 1950's imagery while the 1980 era geodatabase included land cover from both the 1950's and 1980's imagery. The 2009 era geodatabase included land cover codes for all of the 1950's, 1980's, and 2000 era imagery. In addition, the 1980 and 2000 era geodatabases both included attributes that described successional, disturbance, anthropogenic and geomorphic change types, interpreted vegetation species and other data that was captured through image interpretation. The geodatabases contain AOI boundaries, fully attributed land cover polygon layers, and topology verification rules for both LACL and KEFJ. SMUMN also provided specific deliverables listed below, packaged into a zipped file for submission:

- Two, 1950s era, ESRI feature datasets including areas of interest boundaries and polygons mapped to NLCD for LACL and KEFJ;
- Two1980s era, ESRI feature datasets including areas of interest boundaries and polygons mapped to NLCD, NVCS, and geomorphic changes for LACL and KEFJ;
- Two 2000s era, ESRI feature datasets including areas of interest boundaries and polygons mapped to NLCD, NVCS, and geomorphic changes for LACL and KEFJ.
- A single geodatabase was created that included all of the final deliverable feature classes. Metadata was included for the geodatabase.

Project Report

The final project report included all of the procedures, tools, metadata and other resources used in the preparation of the final land cover map product as well as a summary of the project and completeness of the final map product.

Mapping and Classification of Vegetation and Change

The National Land Cover Dataset (NLCD) was utilized and hybridized to accommodate data that was of unique interest to the NPS (**Appendix B**). Approximately 33 of the 90 land cover classification attributes were used from the hybridized National Land Cover Dataset (NLCD) for the project classification. Dominant land cover attributes were identified successfully. Several examples of the most common land cover classification in the project follow on pages below.

Land Cover code 50: Shrublands (**Figure 24**). These areas were characterized by natural or semi-natural woody vegetation with stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that were small or stunted because of environmental conditions were included.

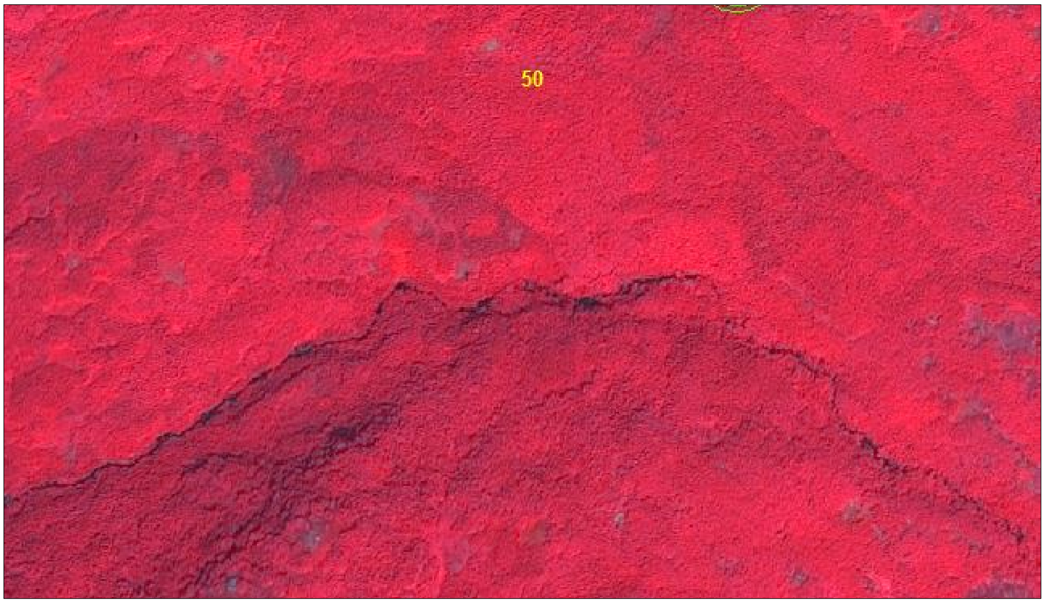

Figure 24. Example of Shrublands, Lake Clark Pass, CIR IKONOS, 2005-2009.

Land Cover code 30: Barren (**Figure 25**): These areas were characterized by bare rock, gravel, sand, silt, clay, or other earthen material, had little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, was more widely spaced & scrubby than that in the "green" vegetated categories.

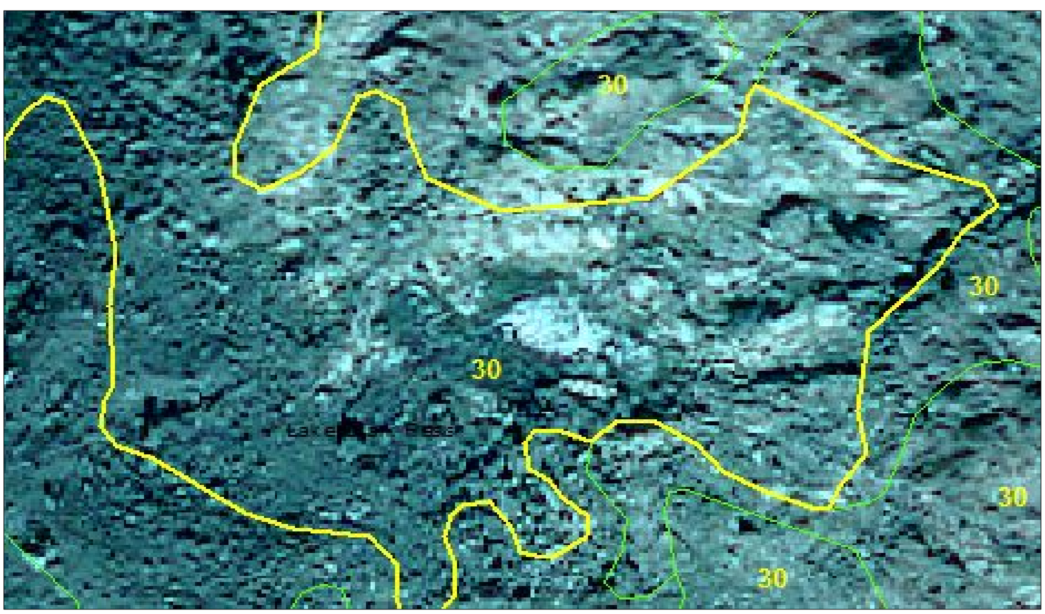

Figure 25. Example of barren, Lake Clark Pass, IKONOS, CIR imagery, 2005-2009.

Land Cover code 45: Deciduous Woodland (**Figure 26**). These areas were dominated by trees generally greater than five meters tall, and had 25% to 60% of total vegetation cover. More than 75 percent of the tree species were the type that shed foliage simultaneously in response to seasonal change.

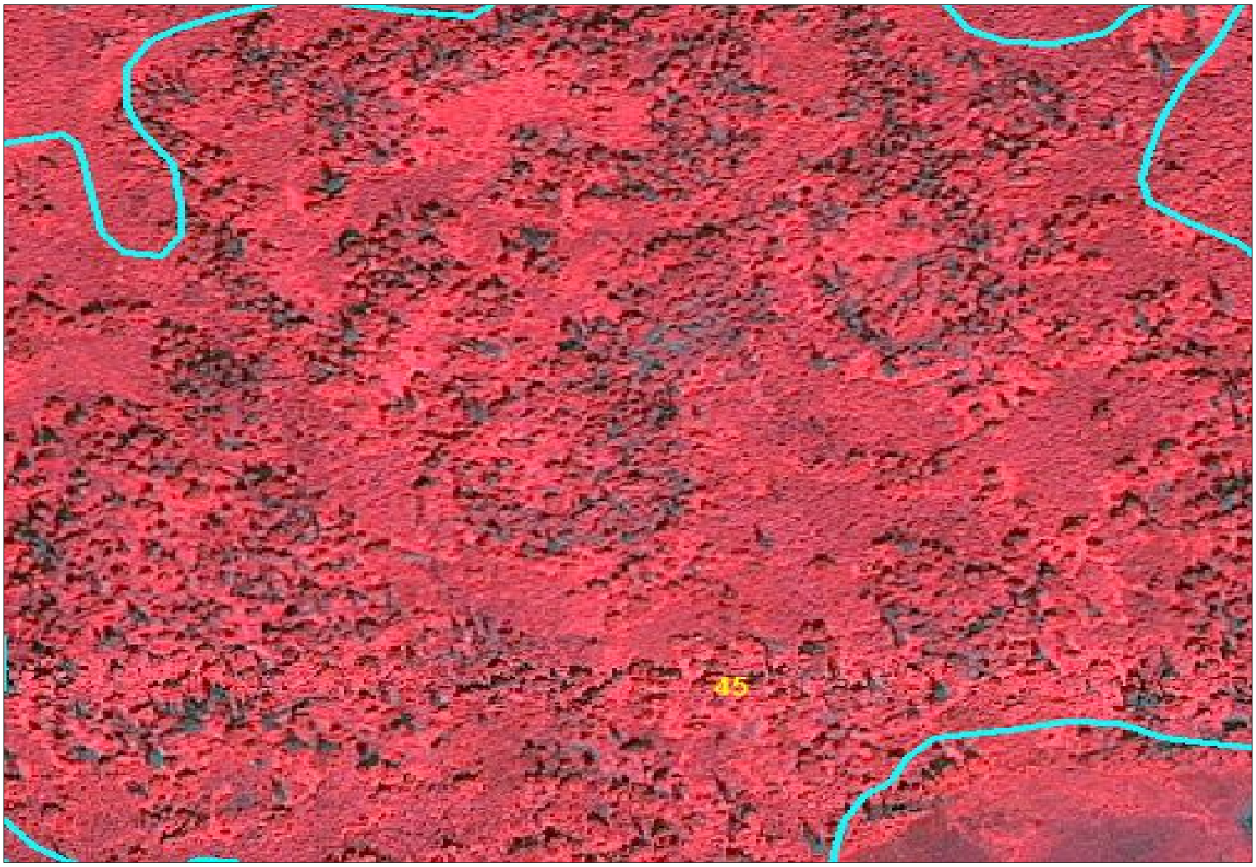

Figure 26. Example of Deciduous Woodland Tuxedni Bay, LACL, IKONOS, CIR, 2005-2009. Patches of coniferous cover are also present.

Land Cover code 75: Herbaceous/shrub sparse upland (**Figure 27**). These areas are characterized by herbaceous and shrub vegetation. Class is typically sparse, generally   20% of total vegetation and are commonly found in recently de-glaciated areas.

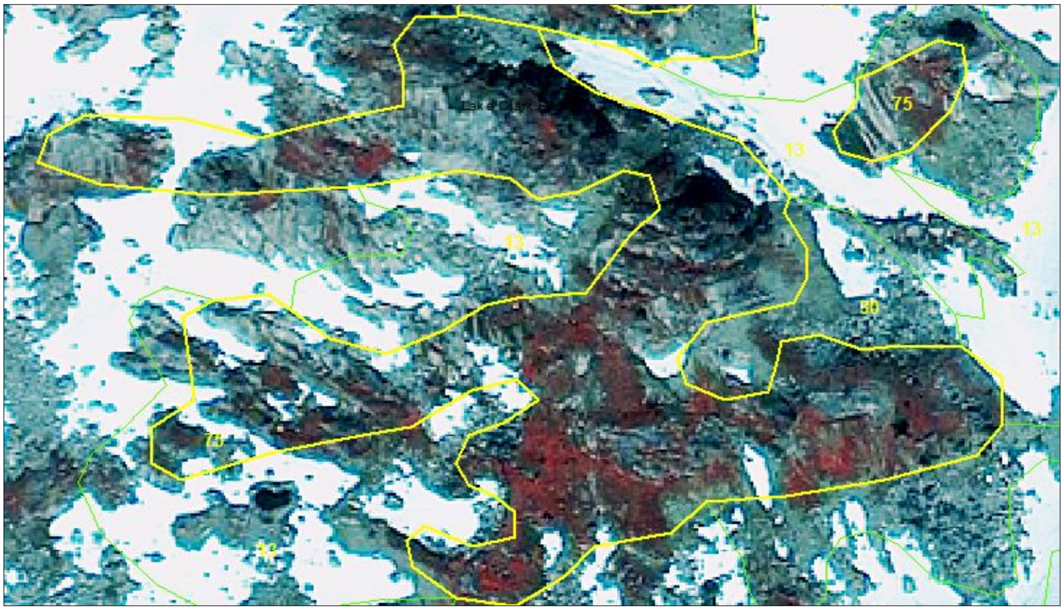

Figure 27. Herbaceous/Shrub Sparse Upland, Lake Clark Pass, IKONOS, CIR, 2005-2009.

Land Cover code 70: Herbaceous Upland (**Figure 28**). Upland areas were characterized by natural or semi-natural herbaceous vegetation. Herbaceous vegetation accounted for 75-100 percent of the cover.

Vegetation changes such as openings, closures or the establishment of new vegetation were delineated and classified. These change codes were then populated in the geodatabases (1980s and 2000 era geodatabases).

Geomorphic changes were also delineated and classified. Some of these changes included outflow lake drainage change revealing natural processes underway including glacial recession, landslide, and/or ice avalanches. Channel formation and migration from ice loss/glacial retreat was also captured and classified as a geomorphic change. In particular “coastal uplift” was captured and classified as a geomorphic change in the Chinitna Bay AOI. Finally, changes in beaver activity were also noted, especially for the Lake Clark Pass and Tuxedni Bay AOIs. Again, all change codes reside in the appropriate geodatabase where the information may provide the opportunity for further analysis by regional natural resource managers.

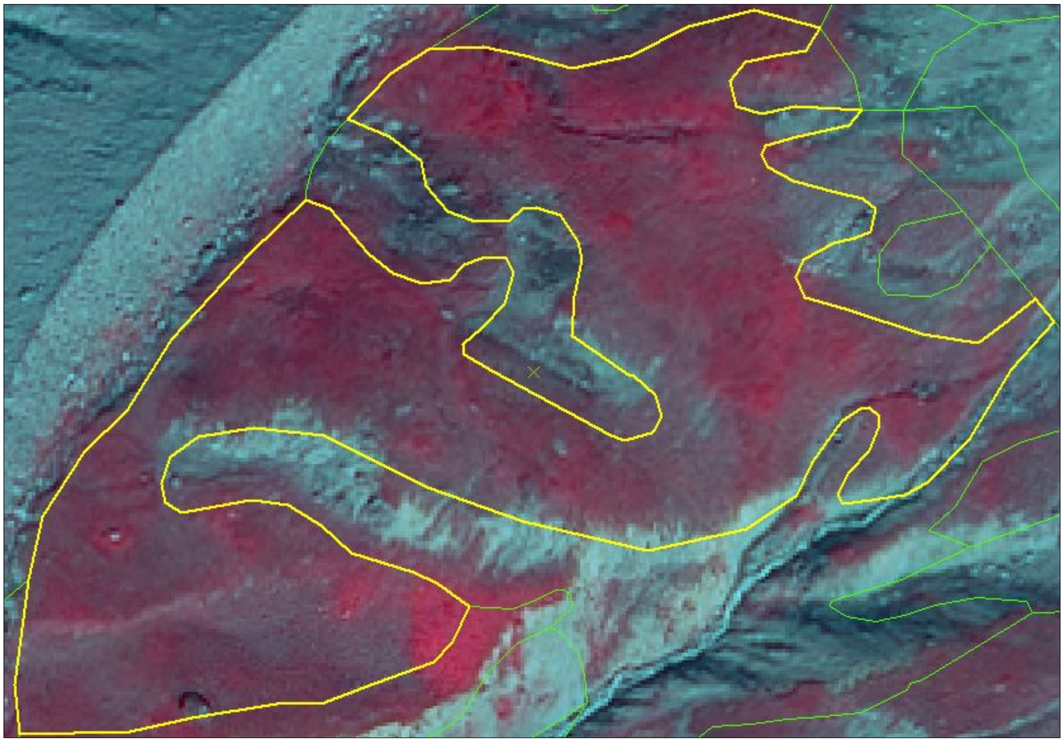

Figure 28. Example of Herbaceous Upland, Lake Clark Pass, IKONOS, CIR, 2005-2009.

Discussion

Overview

The time series image interpretation process discussed in this report was developed specifically for this project. At the outset, SMUMN GeoSpatial Services and NPS team members worked collaboratively to define a workflow that was expected to produce a meaningful digital description of landcover change over time within select locations of LACL and KEFJ National Parks.

There were a few limitations that influenced the workflow process including the variable characteristics and quality of the base imagery, assumptions about the natural processes affecting landcover change, adequacy of the image interpretation process for capturing subtle land cover changes, local knowledge of the image interpreter, and, the available meaningful collateral data.

The mapping and classification of landcover for this project required the use of various imagery types collected using different technologies captured over a period of 60+ years. This resulted in particular challenges related to the mapping and classification process.

All of the imagery used in this project contained unique issues which required consideration by the image analyst. Particular image issues included shadowing, smearing, image shifting, emulsion or variations in resolution. Use and comparison of imagery which had been collected during various seasons or climate conditions over several years was another significant change. Specific challenges and considerations unique to the various images taken during the 1950s, 1980s and 2000s are discussed in more detail below.

Image Challenges

Image Shadowing

Shadow and shade due to sun angle and topography was a challenge from the onset of the research project. Imagery from all three time steps in both LACL and KEFJ had localized areas that were completely within shadows.

In order to effectively interpret, classify, and delineate land cover change, land surface needs to be illuminated. Without positive identification of land surface features or land cover change over time the assignment of the correct classification code was not possible. Therefore, shadow areas found in the imagery were classified in the geodatabase as having “image issues.” This classification code also included poor mosaic development, image shift, image smear, displacement, emulsion, and resolution (discussed below). The creation of an “image issue” category in the classification system helped resolve the issue of “nulls” in the database and preserved line work integrity (**Figure 29**).

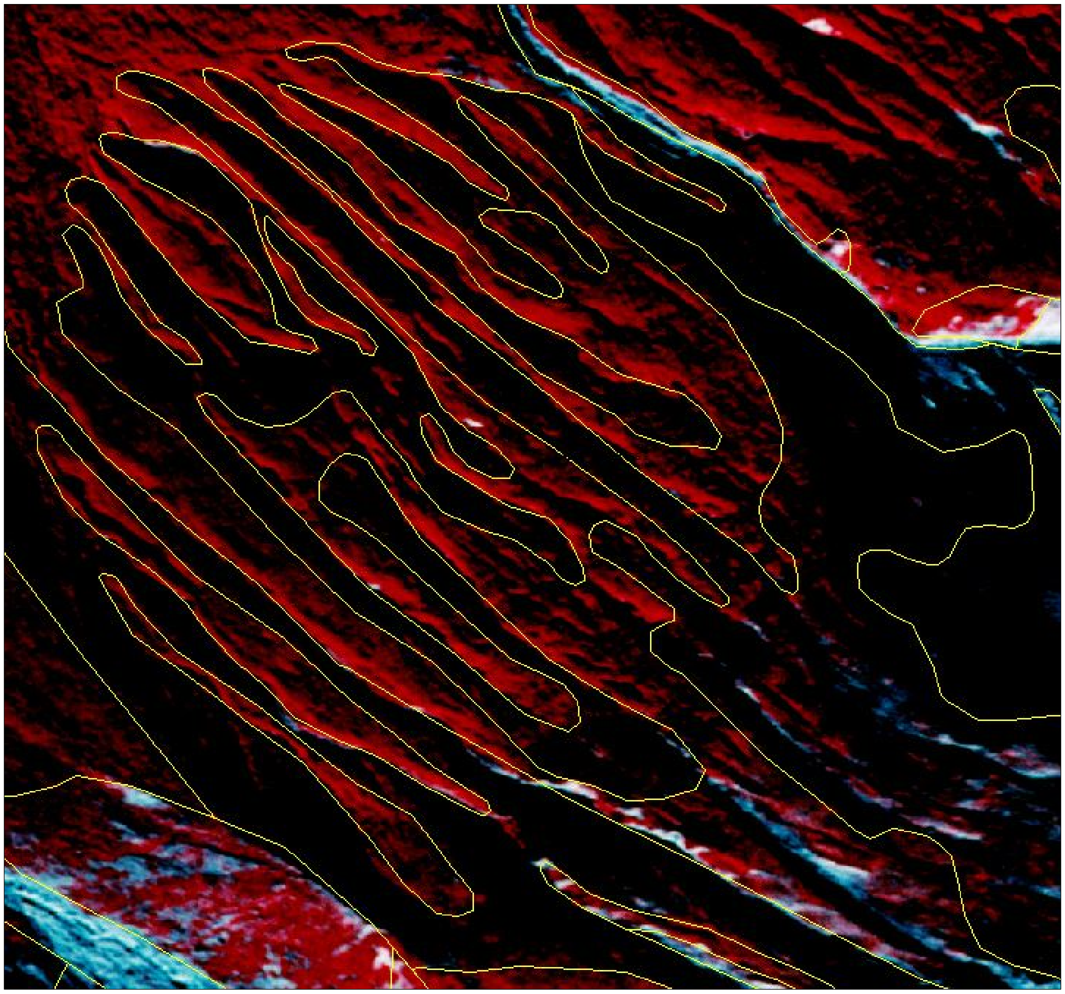

Figure 29. Example of heavy shadowing in Lake Clark Pass AOI. Image from June 20, 1978.

Image Smear

Image smear was also identified in certain areas during the image interpretation and ***classification process. These issues appeared to occur toward the outer edges of the 1950s*** orthorectified black and white imagery for AOIs in both LACL and KEFJ parks. Based on previous analyses conducted by SMUMN, image smear was likely due to a combination of factors. The speculation was that these photos probably contained a significant amount of radial displacement and lens aberration caused by the older camera technology employed during photo acquisition. Having no camera calibration reports available for software adjustment during the orthorectification process may have contributed to the smearing effect (**Figure 30**). It is also possible that the composite DEM and significant elevation changes over short distance were part of this problem.

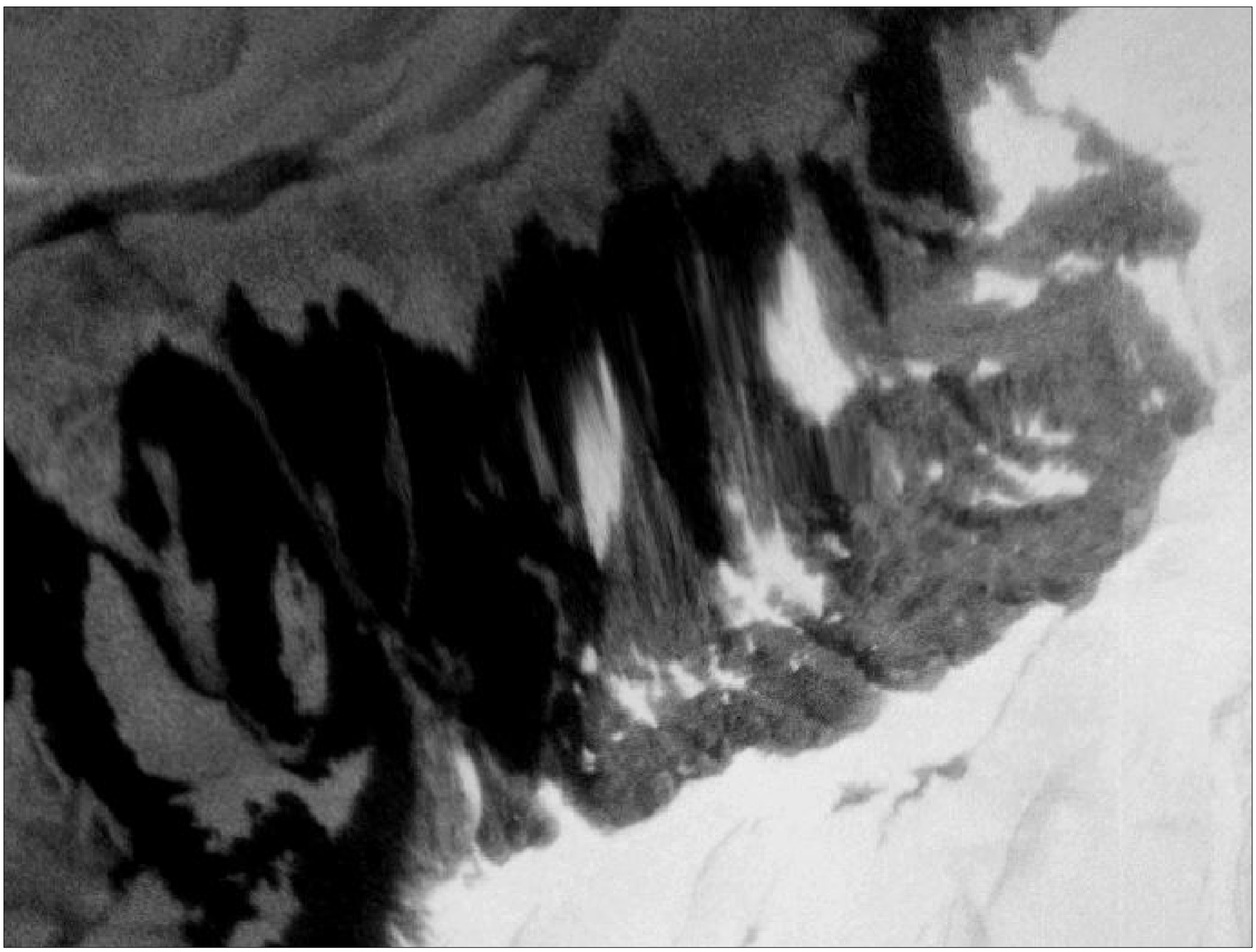

Figure 30. Example of image smear, LACL B/W, 12 July 1954.

Image Shift

Image shift presented the most difficult obstacle to overcome in order to interpret, classify, and delineate land cover change for both LACL and KEFJ parks. Although the image shift was within specifications of the National Map Accuracy Standard for 1:63.360 spatial data (+/- 105.60 feet or +/- 32 meters), it was variable across image frames and years. Areas of Tuxedni Bay (**Figure 31**) viewed in the example below illustrate the challenge of image shift for the image analyst. Within the LACL, Lake Clark Pass AOI approximately 10,000 acres of image shift were identified in the 1980s ortho image layer. It is important a skilled image interpreter be familiar with this challenge during mapping projects. The image interpreter addressed these variances by consistently detecting their presence, completing classifications and commenting “image shift” in the attribute table of the geodatabase.

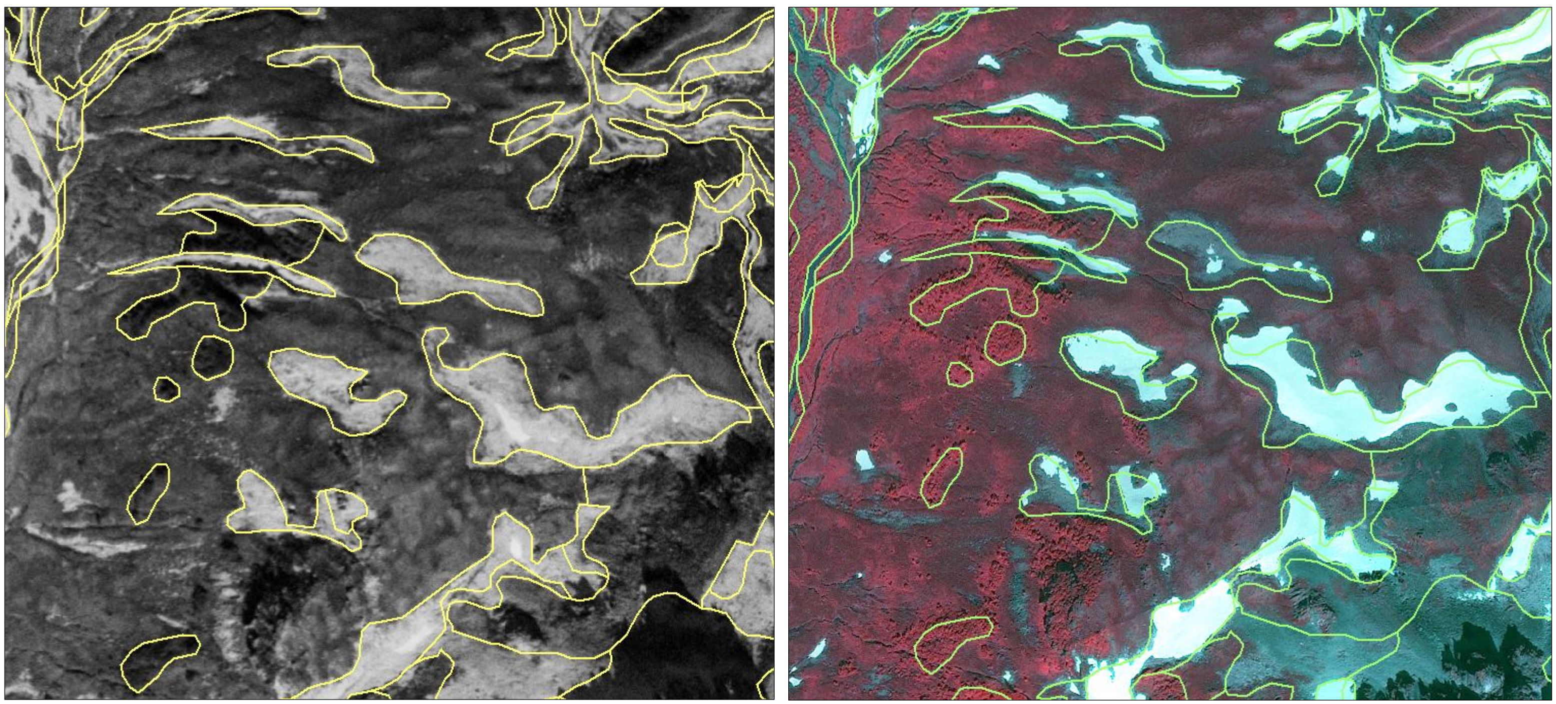

Figure 31. Example of image shift, Tuxedni Bay AOI, LACL. Image on the left was taken in August, 1957 (left). The AHAP image (right) was captured 21 years later on August, 1978.

Emulsion Issues

A key component of photo analysis is the ability to identify and interpret subtle changes in textures, tones, color hues and signatures of features on land surfaces. Emulsion is the substance on the surface of photographic film or paper that makes it react to light. Older cameras and developing technologies in the 1950's resulted in the absence of separation of the colors, thus resulting in more emphasis being put on textures for various features.

Another imagery challenge stemmed from the representation of subtle landcover changes on the 1950s black and white images. Given that this imagery was only single band black and white, it was not as responsive to landcover changes as multispectral imagery. An example of this was the confusion in land cover signatures between low vegetation (e.g. dwarf shrub/herbaceous) and open land covered by sand, gravel or bare rock (**Figure 32**). One option that was employed in an attempt to ameliorate this issue was the use of the Effects Toolbar in ESRI ArcMap. This toolbar was used on just the black and white photos from the 1950s. This allowed the image analyst to adjust contract and brightness in circumstances where features were obscure. In some cases this did allow for improved differentiation of land cover types. This tool did not affect the quality of interpretation.

Figure 32. Example of emulsion, Aialik RS AOI, KEFJ, 1950 B/W imagery. Land cover signatures are more difficult to interpret with this type of imagery.

Resolution Issues

Analysis using imagery from different time periods, cameras or sensors creates additional challenges. Older historical images are processed from hard copy aerial photos. The quality of the photos depends, to some degree, on how the photos were collected and the available technology used during the date of capture.

As noted earlier, hard copy aerial photographs may lose some image quality as a result of final processing steps. Image analysts may then be limited during mapping and classification efforts to what they are able to see on an orthorectified image. For example, spectral signatures may generally be more blended or defined (**Figure 33**).

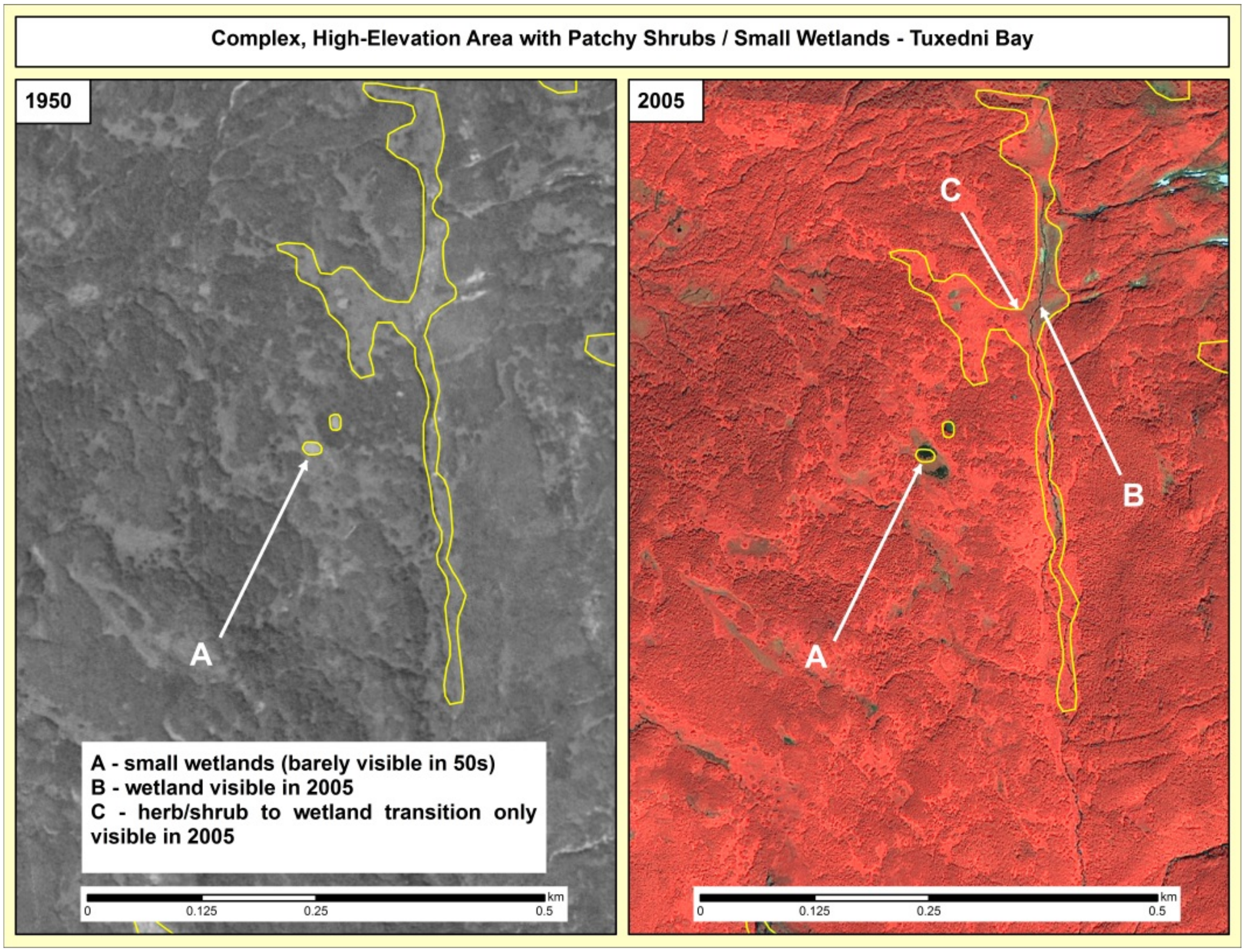

Figure 33. Tuxedni Bay, 1950 B/W photo (left), 2005 IKONOS (right). Land cover features have higher definition in the IKONOS imagery.

Findings

The proposal to employ differing mapping conventions between years was justified as a result of the increased quality of the imagery over time. Although all three eras of digital imagery had one-meter resolution, they each had been captured and converted or produced with varying degrees of quality. The difference in initial quality dictated the mapping convention standard for each of the three mapping time periods.

1950s Black and White

The photography captured during the 1950s served as an important point in time record and baseline from which to compare land cover changes over time for all AOIs in this project. The black and white photography did affect image emulsion, resolution and the ability of the interpreter to determine vegetation signatures in comparison to imagery captured in color. It is important that image analysts working with this type of photography be experienced and discerning while interpreting features viewed in this historical imagery's many shades of white, grey and black (**Figure 34**).

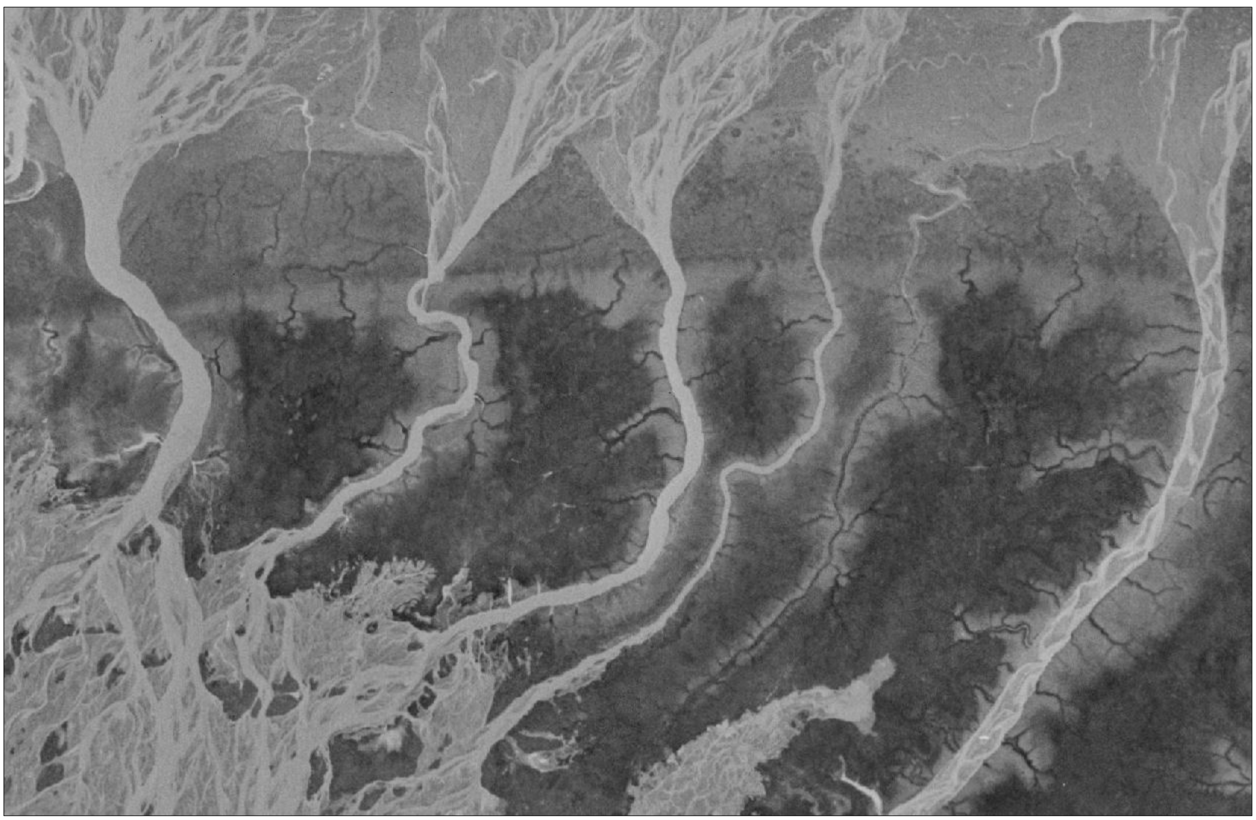

Figure 34. Black and White Photo, Tuxedni Bay, 1950s. The delineation and classification of land codes for this area included hundreds of individual features. The interpreter must be skilled at noting shades of white, grey and black.

1980s AHAP

The delineation of features using the 1980s imagery while the 1950s layer was also available for viewing was important for two reasons: The first was to maintain the integrity of the line work. The second reason was to show an accurate transition between the different time periods. In order to delineate change over time, it was crucial that polygons were not modified or merged from the other time periods. All delineated polygons needed to accurately capture the feature for each time period.

Because the AHAP imagery was in color infrared it provided enhanced resolution for signatures. Tones of water, vegetation, and geomorphic features, were more vibrant and distinguishable. This image layer also revealed the first evidence of land cover change over time (**Figure 35**).

Figure 35. AHAP imagery, Tuxedni Bay, 8/27/1978. Color provided distinguishable land covers.

2000s IKONOS

The most informative of the three image data sets was the CIR IKONOS, 2006-2010. This third time step imagery, captured most recently, provided the best resolution to a 1:5.000 scale. The quality of resolution was superior to the previous two time-steps; the image's tones, signatures and textures made photo interpretive calls easier. By reordering the band combinations of the IKONOS imagery, a range of tones, textures, and hues were intensified and thus authenticated many interpretation decisions.

With the 1950s and 1980s delineation complete, an original delineation of the 2000 imagery was digitized. This third time step was then compared from1954 through the IKONOS 2006- 2010 imagery (**Figure 36**). Delineation from all three time steps was reviewed to determine if change, or no change, had occurred.

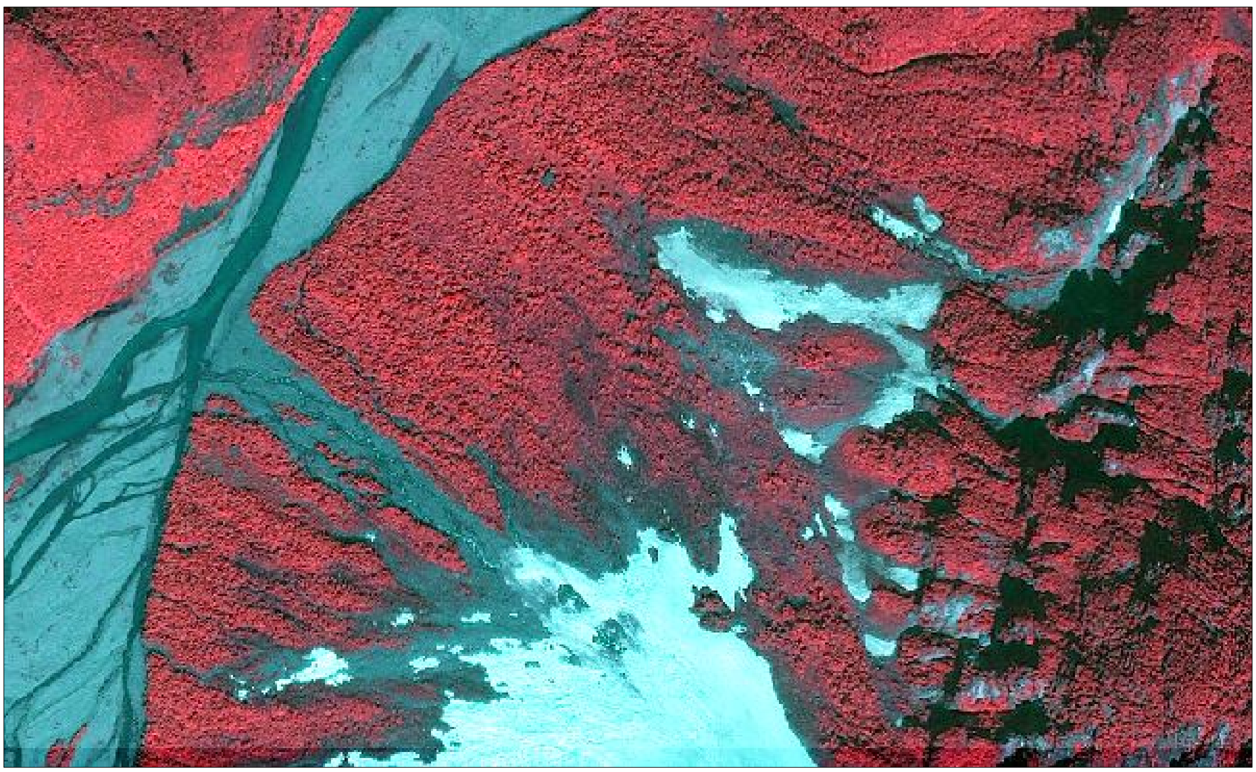

Figure 36. IKONOS CIR 2006-2009 imagery, Tuxedni Bay, Lake Clark Pass, LACL.

Interpretation of IKONOS imagery was at times difficult. Understanding the properties inherent in the image such as emulsion, tone, texture, signature, and scale were important factors. At times, performing analysis on the terrain characteristics also required changing the bands combinations for the IKONOS to view the image in false color CIR. (**Figure 37**).

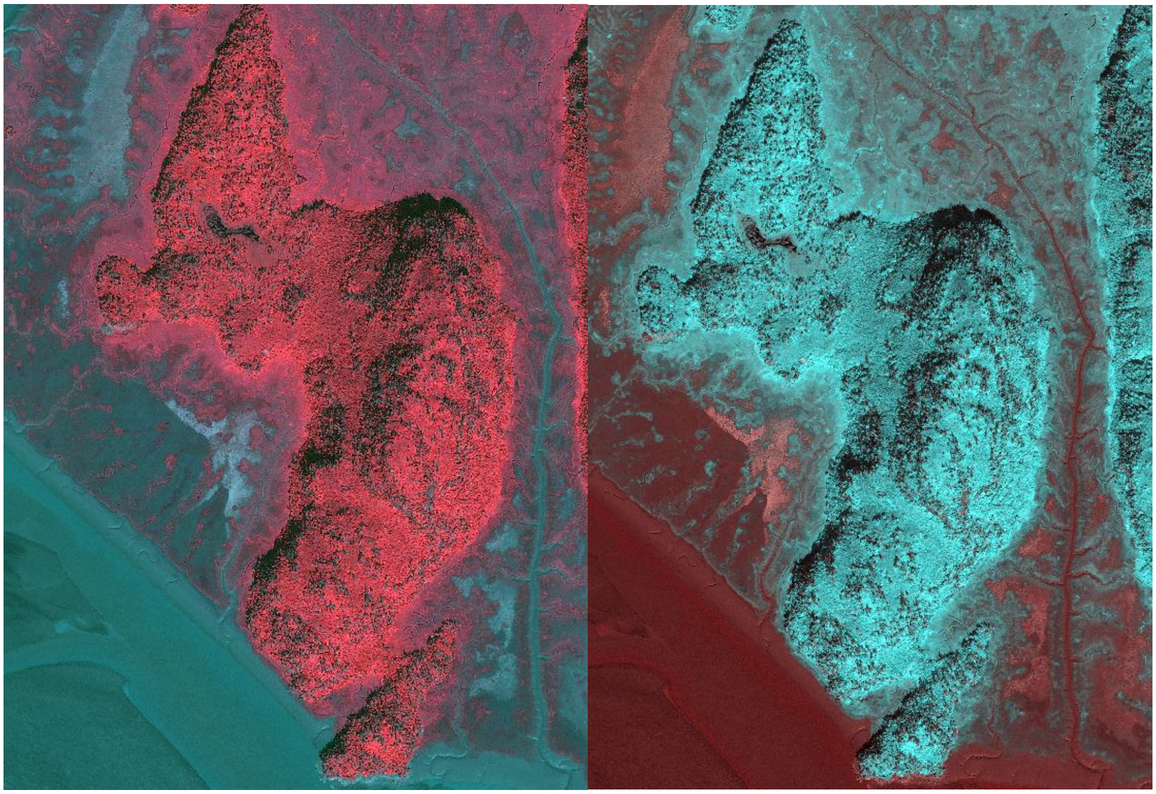

Figure 37. Example of band reordering which provided clarity, LACL.

Mapping and Classification of Geomorphic Change

Geomorphic changes processes such as coastal subsidence/flooding and coastal uplift were, at times, difficult to identify from image analysis. Geomorphic processes included mass wasting, channel formation and/or wetland creation. In areas where these processes were suspected to be at work, corroboration with local and regional experts from the NPS staff was important.

Photo Interpretation Observations

The primary purpose of this project was to capture change over time. Interpretation, classification, and delineation of land cover were determined for three time steps. Consistency in photo interpretation was crucial in achieving this goal. The development of a hybridized hierarchical classification provided the parameters by which land cover change was derived from interpretations for each of the individual time steps: 1954-1984, 1984-2009, and 1954-2009. A primary task was maintaining a level of consistency on interpretation calls and change classes across all three time periods and in the wide variety of landscapes. For example, a polygon feature classified with a signature, texture, and tone characteristic of “barren” in 1954 was consistently applied to all features identical in appearance. Consistency in photo interpretation creates credible data while inconsistent interpretation leads to unreliable data or the potential for flawed analysis.

Lake Clark Pass AOI and Northeastern Glacier AOI revealed a substantial amount of ice loss/glacial retreat over the three time steps. The information in the completed geodatabase will allow NPS staff to complete further change analysis. Based on the project data from the three time periods, it was noted that the glaciers within LACL National Park and Preserve and KEFJ National Park were trending toward further ice loss and glacial retreat.

The Lake Clark Pass AOI showed the transformation of the land surface from what once was a heavily glaciated valley, to outflow lakes, as seen in imagery from 1954. The change was due to outflow lake drainage (seen in the 1980s imagery), followed by vegetation establishment in the IKONOS imagery of 2006. Outflow lakes are often the result of many natural mechanisms. Quite possibly, a range of factors might have contributed to the lake drainage including glacial recession and/or degradation of ice or moraine features; ice avalanches, beaver dam breach, tectonic activity, or landslides.

Other changes in land cover were recorded. For example, vegetation expansion within the intertidal area of the Tuxedni Bay AOI over the three time periods revealed considerable vegetation establishment and growth. Channel formation and migration was also observed over the three time periods in various areas of the Chinitna Bay, Lake Clark Pass, Tuxedni Bay, and Northeastern Glacier AOIs.

Other aspects of land cover change were of particular interest to NPS staff. As the project progressed, NPS expressed an interest in determining whether beaver activity might be identified in any of the imagery captured over time, and whether the imagery would be of fine enough resolution to show loss of lichen cover due to shrub expansion. Beaver activity was captured and classified as geomorphic change in the Lake Clark Pass and Tuxedni Bay AOIs. A hybridized code used to identify lichen dominated shrublands was also developed and used to track changes in lichen cover. A decrease in lichen cover was recorded, especially in the Caribou Lakes AOI. The information about the extent of particular vegetation types (for example lichen) will provide park managers with the opportunity to analyze important food sources for wildlife.

The image interpreter also took note of unique changes observed in the Chinitna Bay AOI. As photo analysis and delineation moved forward (over time), something about this area appeared different than the other AOIs within LACL National Park and Preserve and KEFJ National Park. After consultation with the SMUMN team, it was determined that this AOI was possibly located within the zone of coastal uplift and subsidence. Further confirmation was requested from regional NPS experts to validate this observation. The collaborative efforts of the NPS team in identifying the coastal uplift and subsidence proved invaluable regarding the interpretation for Chinitna Bay. Indeed, there is long history of tectonic activity and earthquakes along the Alaskan coastline which continues to be a subject of interest to the scientific community.

Use of Alaska's Statewide Mapping Initiative Sources

Collecting all primary and collateral data sources for this project was a crucial step in the Methodology of this project. The image interpretation and classification of land cover change in LACL and KEFJ National Parks between 1954 and 2009 required primary data imagery from three time steps. SPOT5 imagery from Alaska's Statewide Mapping Initiative was also used when other primary image sources were inadequate.

As noted earlier in this report, certain areas of the IKONOS imagery (2006-2010) included shadowing or cloud occlusions which prevented positive identification of land cover features (**Figure 38**). To resolve these issues, the code "999" was initially recorded in the attribute table which notated that these features were not able to be attributed. The code was used exclusively in situations where classification was undetermined.

The use of available SPOT5 imagery was a valuable dataset for this project. As a collateral data set, SPOT5 was useful to support IKONOS based decisions. SPOT5 was also useful as an alternative data set for delineation of land surface features when clouds were present in the IKONOS imagery (**Figure 39**). The SPOT5 imagery was captured between 2010 and 2011 and so was close to the time period that the IKONOS imagery was taken. SPOT5 was also comparable because the imagery was in CIR and had a 2.5 meter resolution. SPOT5 was only utilized in isolated areas where cloud occlusion occurred in the IKONOS imagery. As a result, it reduced or eliminated many areas that would otherwise have been coded "999" (unattributable). The interpreter took into account possible differences between these two image types and concluded that they were similar enough for use in this project in special circumstances as noted above. No significant vegetation or geomorphic changes were recorded as a result.

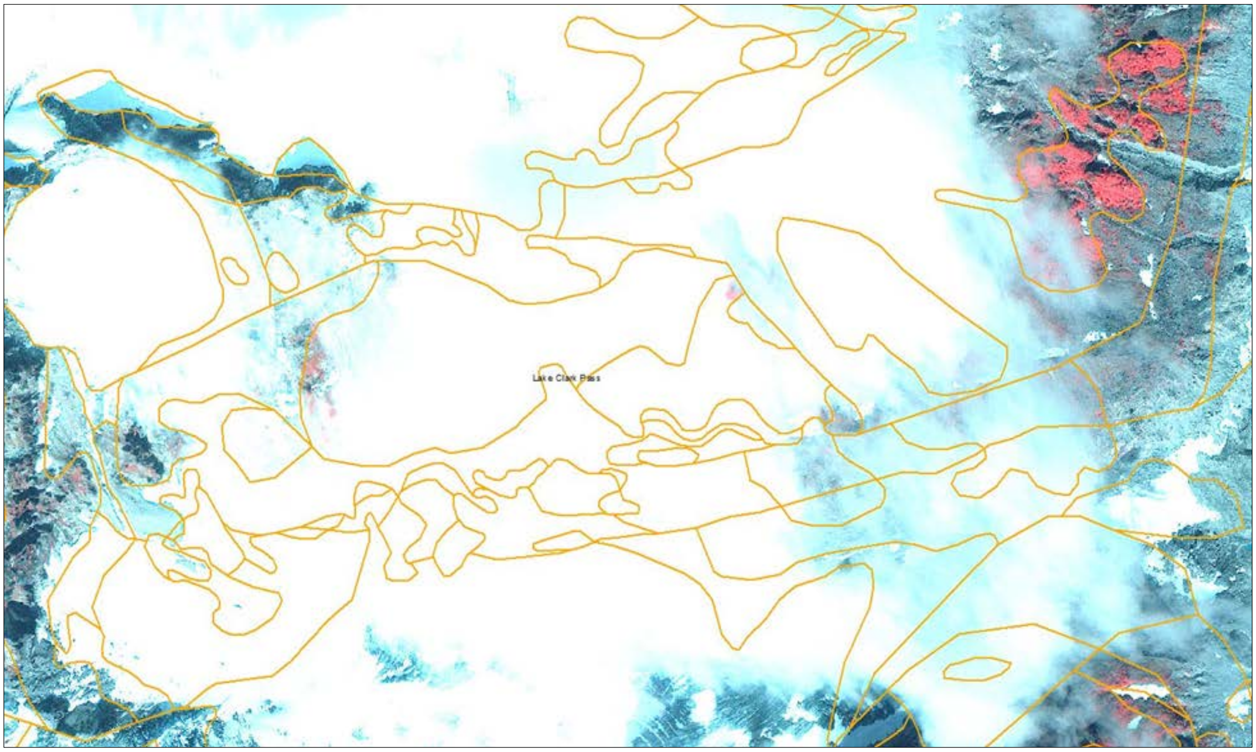

Figure 38. Example of cloud occlusion, Lake Clark Pass, LACL, 1978.

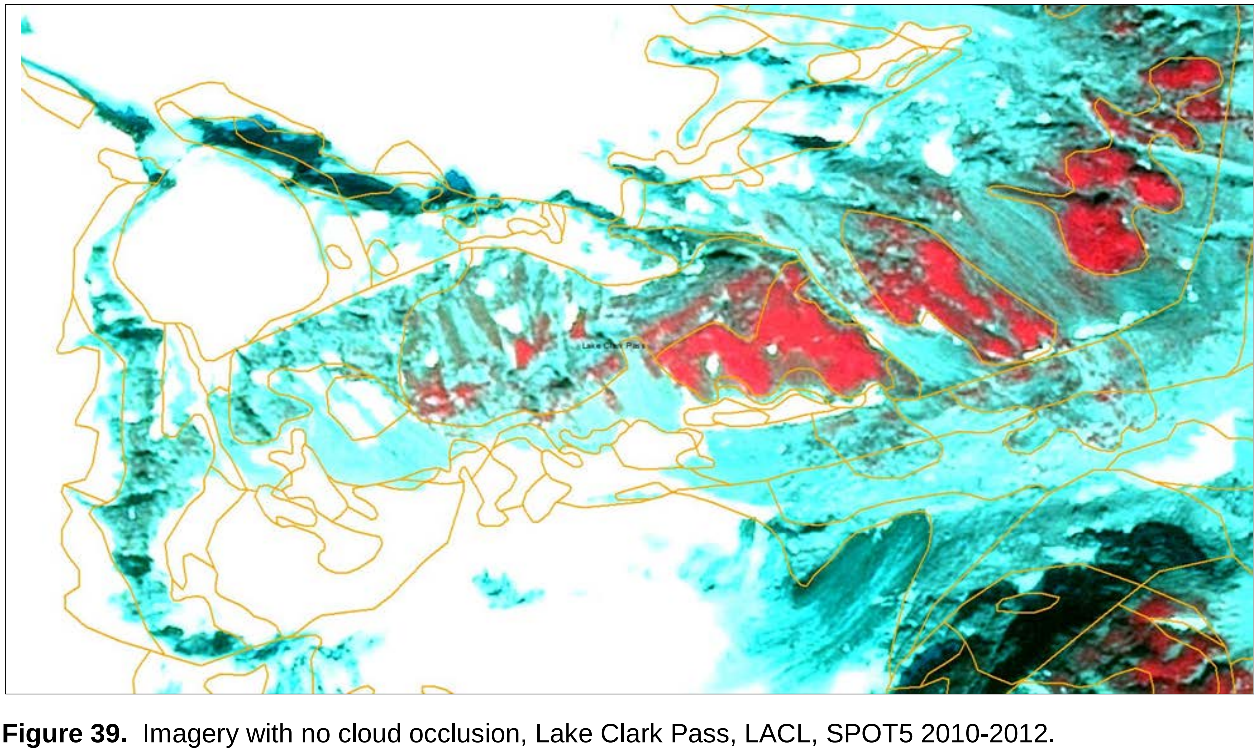

Figure 39. Imagery with no cloud occlusion, Lake Clark Pass, LACL, SPOT5 2010-2012.

Photo Positioning Considerations

Photo positioning is another consideration before delineation and classification began. The nearer the features were to nadir, the greater the accuracy was to the land surface. In other words, the further away the ortho was from nadir, the greater the distortion (**Figure 40**).

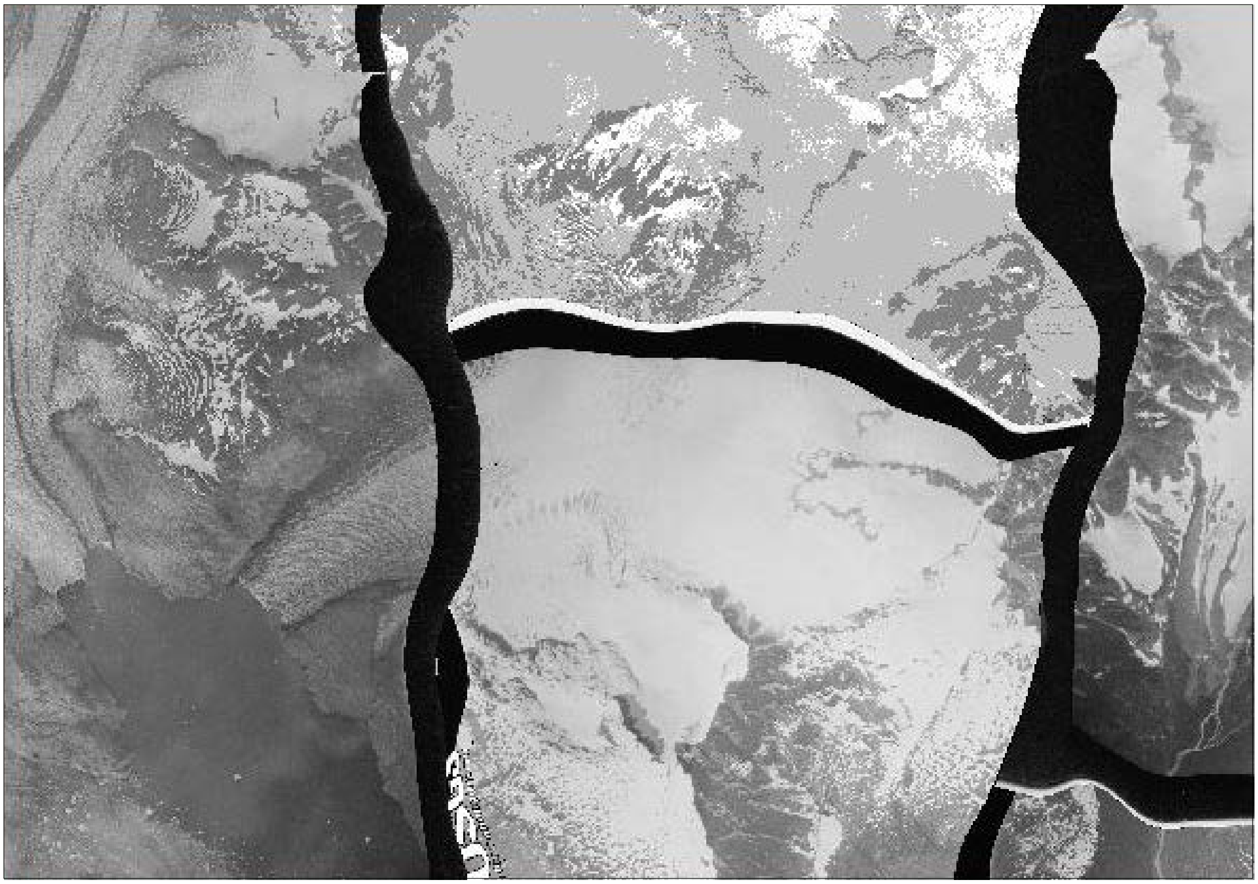

Figure 40. Example of multiple ortho images. Northeastern Glacier, KEFJ, 1950 B/W orthos.

In the case of the Northeastern Glacier AOI, multiple images were available in black and white but only two images were identified to be the best fit for delineation and classification purposes. The process of selecting imagery closest to its nadir determined which ortho image was ultimately used (**Figure 41**).

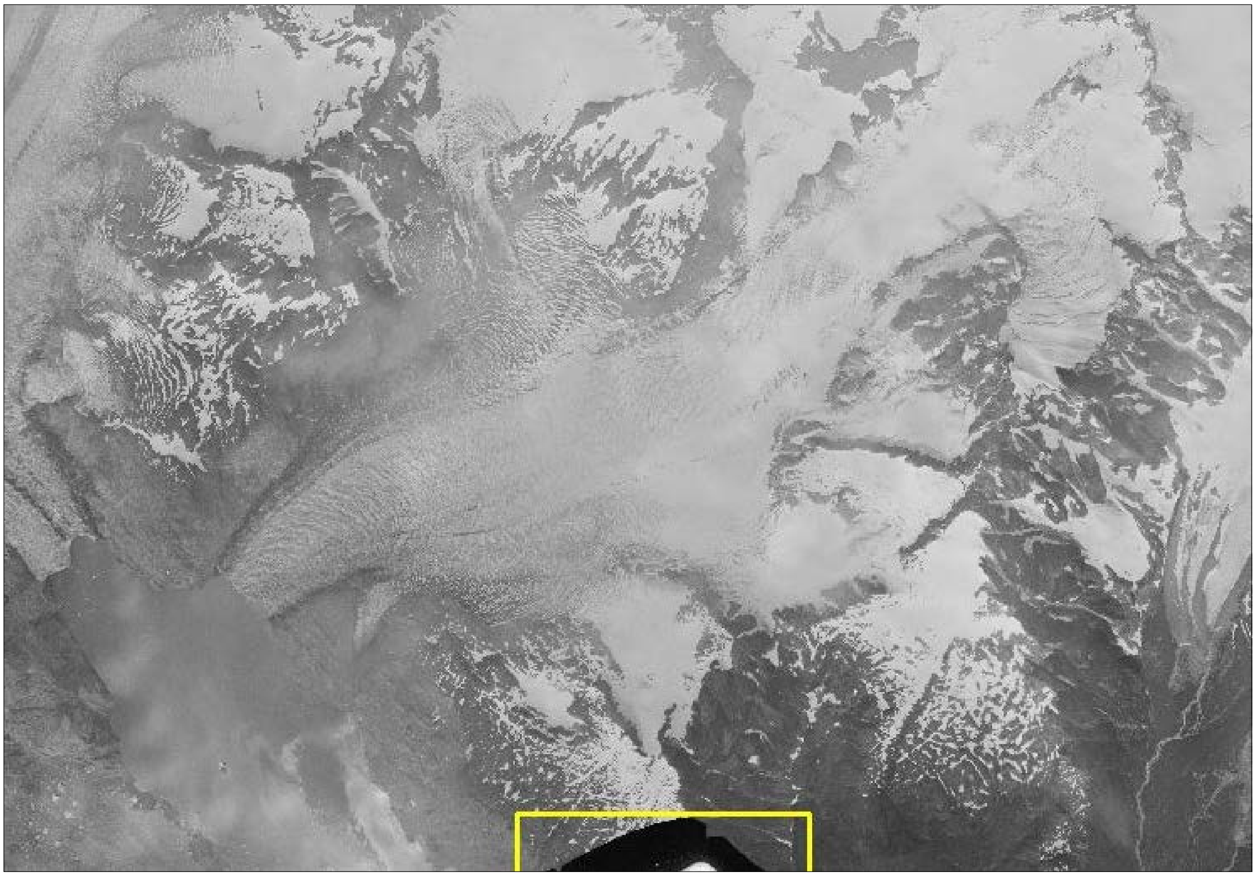

Figure 41. Example of an ortho where the nadir (ortho center), exhibited the least amount of distortion. Northeastern Glacier AOI, KEFJ, B/W, 1950 photograph. Note yellow box and black area at the center bottom of this image (black area) which indicates a gap in the imagery.

Conclusions

The research undertaken as part of this report supported the following conclusions:

1. The methodology used in this project provided a valid approach to record point-in-time landscape conditions which may be used to assess changes in ecosystem characteristics;
2. The resulting data from this project was designed to be reproduced and utilized by other users;
3. Image interpreters need to be experienced and familiar with the study area vegetation types and change processes. This would be best accomplished with the benefit of field trips or ground level and oblique photos and vegetation plots.
4. Several image challenges must be considered and addressed. These include image shift, displacement, smear, shadowing, mosaicking, emulsion, and resolution of scale;
5. Alaska's Statewide Mapping Initiative program and SPOT5 imagery may be useful for unattributable features (999) when IKONOS imagery is not conclusive;
6. The NLCD system was satisfactory for classifying land cover but, once hybridized, provided for unique regional analysis;
7. The image interpreter benefits from a physical science background; advisable for coding geomorphic processes especially;
8. Change types are limited to those that can be identified and interpreted on the imagery.

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APPENDIX A: Hybridized NCLD Land Cover Classification - Code Table and Descriptions

Table of Codes, Sub codes, Description and Interpretation Comments				
NLCD Code	**NLCD Description**	**Sub code**	**Sub code Description**	**Comments for LACL and KEFJ**
10	Water	1	high gradient stream	Water on ice?
11	Open Water	2	river	
		3	rill	
		4	intertidal	Reserved for areas that are open water but not really differentiated between rill channel and part of the bay, for example
		5	river cutting through estuary	
		6	lake	
		7	pond	
12	Perennial Ice/Snow			Difficult to determine if it is truly perennial or seasonal (annual) snow
13	Annual Snow			This is a proposed class to deal with early imagery
30	Barren			
		2	braided river	
		8	mountain slope or talus	
		9	wash	
		10	rock	
		11	high gradient stream	
31	Barren Land			Reserved for glacier debris/partial glacier melt
32	Unconsolidated Shore			Reserved for beaches and glacier river/stream silt?
		1	sand/gravel	
		2	braided river	
		3	mud flats	
		4	intertidal	
		5	river cutting through estuary	
40	Forested Upland			Reserved for forested areas in which differentiation is not possible
41	Deciduous Forest			Aspen, some birch?
42	Evergreen Forest			Black or White spruce
43	Mixed Forest			
44	Deciduous Woodland			
45	Evergreen Woodland			

Table of Codes, Sub codes, Description and Interpretation Comments				
NLCD Code	**NLCD Description**	**Sub code**	**Sub code Description**	**Comments for LACL and KEFJ**
46	Mixed Woodland			
47	Deciduous Sparse Woodland			
48	Evergreen Sparse Woodland			
49	Mixed Sparse Woodland			
50	Shrubland	2	braided river	Alders (thick shrubs that aren't along a river)
51	Dwarf Shrub			Empetrum Heath
52	Shrub/Scrub			Birch
53	Multi-level canopy, shrub dominant			
54	Multi-level canopy, coniferous tree dominant			
55	Multi-level canopy, deciduous tree dominant			
70	Herbaceous Upland			
71	Grassland/Herbaceous			
72	Sedge/Herbaceous			
73	Lichens			
76	Lichens/shrub sparse upland			
74	Moss			
75	Herbaceous/shrub sparse upland			
90	Woody Wetlands			
91	Palustrine Forested Wetlands			
92	Palustrine Scrub/Shrub Wetlands			
93	Estuarine Forested Wetland			
94	Estuarine Scrub/Shrub Wetland			
95	Emergent Herbaceous Wetlands			
96	Palustrine Emergent Wetland			
		6	undifferentiated shrub and herbaceous	
97	Estuarine Emergent			

Table of Codes, Sub codes, Description and Interpretation Comments				
NLCD Code	**NLCD Description**	**Sub code**	**Sub code Description**	**Comments for LACL and KEFJ**
	Wetland			
		4	intertidal	
		6	undifferentiated shrub and herbaceous	

Multi-Resolution Land Characteristics Consortium (MRLC)
National Land Cover Data (NLCD) Classification Schemes Definitions

Definitions

NLCD 2001 Land Cover Class Definitions

10. Water - All areas of open water or permanent ice/snow cover.

11. Open Water - All areas of open water, generally with less than 25% cover of vegetation or soil.

12. Perennial Ice/Snow - All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

20. Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).

21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large -lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

30. Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive

31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

32. Unconsolidated Shore* - Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms representing this class.

40. Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

50. Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co- associated with grasses, sedges, herbs, and non-vascular vegetation.

52. Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

70. Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grassland/Herbaceous - Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing

**** C-CAP data only***

72. Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.

73. Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.

74. Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.

80. Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

90. Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

91. Palustrine Forested Wetland* - Includes all tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

92. Palustrine Scrub/Shrub Wetland* - Includes all tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. The species present could be true shrubs, young trees and shrubs or trees that are small or stunted due to environmental conditions.

93. Estuarine Forested Wetland* - Includes all tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

**** C-CAP data only***

94. Estuarine Scrub/Shrub Wetland* - Includes all tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

95. Emergent Herbaceous Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

96. Palustrine Emergent Wetland (Persistent)* - Includes all tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Plants generally remain standing until the next growing season.

97. Estuarine Emergent Wetland* - Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Perennial plants usually dominate these wetlands.

98. Palustrine Aquatic Bed* - The Palustrine Aquatic Bed class includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages.

99. Estuarine Aquatic Bed* - Includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages.

**** C-CAP data only***

<u>NLCD 1992 Classification System</u>
10. Water - All areas of open water or permanent ice/snow cover.

11. Open Water - all areas of open water, generally with less than 25% cover of vegetation/land cover.

12. Perennial Ice/Snow - all areas characterized by year-long surface cover of ice and/or snow.

20. Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).

21. Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for

20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.

22. High Intensity Residential - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.

23. Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

30. Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

31. Bare Rock/Sand/Clay - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.

32. Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression.

33. Transitional - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.)

40. Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species` maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

50. Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

60. Non-Natural Woody - Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural wood

61. Orchards/Vineyards/Other - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.

70. Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

80. Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

82. Row Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

83. Small Grains - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

84. Fallow - Areas used for the production of crops that do not exhibit visible vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.

85. Urban/Recreational Grasses - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

90. Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water.

91. Woody Wetlands - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

92. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

Appendix B: Hybridized Codes

10. Water - All areas of open water or permanent ice/snow cover.

11. Open Water - All areas of open water, generally with less than 25% cover of vegetation or soil.

12. Perennial Ice/Snow - All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

20. Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).

21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large -lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

30. Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

32. Unconsolidated Shore - Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of land forms representing this class.

40. Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 10-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and 60% to 100%of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and 60% to 100% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and 60% to 100% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

44. Deciduous Woodland - Areas dominated by trees generally greater than 5 meters tall, and 25% to 60% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

45. Evergreen Woodland - Areas dominated by trees generally greater than 5 meters tall, and 25% to 60%of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

46. Mixed Woodland - Areas dominated by trees generally greater than 5 meters tall, and 25% to 60% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

47. Deciduous Sparse Woodland - Areas dominated by trees generally greater than 5 meters tall, and 10% to 25% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

48. Evergreen Sparse Woodland - Areas dominated by trees generally greater than 5 meters tall, and 10% to 25% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

49. Mixed Sparse Woodland - Areas dominated by trees generally greater than 5 meters tall, and 10% to 25% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

50. Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation. This class includes areas of *Empetrum.*

53. Multi-level/Canopy, shrub dominant- Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental **conditions.**

54. Multi-level/Canopy-coniferous tree dominant- Multi-level/Canopy-coniferous tree dominant- Areas dominated by trees generally greater than 5 meters tall, and 60% to 100% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage. This class is characterized by a dense under story vegetation cover

55. Multi-level/Canopy-deciduous tree dominant- Areas dominated by trees generally greater than 5 meters tall, and 60% to 100%of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

52. Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

70. Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grassland/Herbaceous - Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

72. Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.

73. Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.

74. Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation

75. Herbaceous/shrub sparse upland - Areas are characterized by herbaceous and shrub vegetation. This class is typically sparse and generally 20% of total vegetation. These areas are commonly found in recently de-glaciated areas.

76. Lichens/shrub sparse - Areas are dominated by shrubs with lichens typically greater than 30% of the total vegetation. The code also is characteristic of shrub intrusion in otherwise lichen dominated areas.

80. Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

90. Woody Wetlands - Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

91. Palustrine Forested Wetland - Includes all tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

92. Palustrine Scrub/Shrub Wetland - Includes all tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. The species present could be true shrubs, young trees and shrubs or trees that are small or stunted due to environmental conditions.

93. Estuarine Forested Wetland - Includes all tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

94. Estuarine Scrub/Shrub Wetland - Includes all tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean- derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

95. Emergent Herbaceous Wetlands - Areas where forest or shrub vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

96. Palustrine Emergent Wetland (Persistent) - Includes all tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Plants generally remain standing until the next growing season.

97. Estuarine Emergent Wetland - Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Perennial plants usually dominate these wetlands.

98. Palustrine Aquatic Bed - The Palustrine Aquatic Bed class includes tidal and non-tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages.

99. Estuarine Aquatic Bed - Includes tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages.

NVCS - Level IV Species

1. Balsam poplar (*Populus balsamifera*)
2. Black spruce (*Picea mariana*)
3. White spruce (*Picea glauca*)
4. Willow (*Salix sp.)*
5. Birch (*Betula sp.)*
6. Alder (*Alnus sp.*)

Vegetation Changes

1. Spruce closure
2. Spruce establishment/expansion
3. Spruce dieback/stand opening
4. Shrub closure
5. Shrub establishment-This is reserved for situations in which dwarf shrubs, herbaceous, or sparse LC's change into shrubs.
6. Shrub loss
7. Hardwood forest closure
8. Hardwood forest establishment
9. Hardwood forest dieback/stand opening

10. Vegetation establishment-This is reserved for conditions in which LCs change from barren classification to vegetation establishment.

25. Vegetation development/expansion in intertidal area

27. Aquatic bed formation/expansion in Palustrine area-This is reserved for conditions in which LCs change from open water to aquatic bed in palustrine areas.

28. Open Water formation/marine intrusion

29. Beaver Activity- reserved for pond formation in which dam formation or ponding occurs.

<u>Geomorphic Changes</u>

11. Channel formation
12. Channel abandonment
13. Pond drying
14. Pond/Lake Formation-pond formation from beaver activity
15. Wetland loss
16. Wetland creation-
17. Mass wasting
18. Coastal subsidence/flooding
19. Coastal uplift
20. Ash deposit
21. Alluvial deposit
22. Colluvial deposit
26. Ice loss/glacial retreat

<u>Intertidal</u>

23. Rill formation
24. Rill abandonment
25. Vegetation development/expansion in intertidal area
30. Annual snow increase
31. Annual snow decrease
32. Perennial snow increase
33. Perennial snow decrease40 Mixed forest establishment

<u>Image differences</u>

90. Tide position differences between images
999. Shadows/mosaic/image shift/image smears

Appendix C: Imagery Index

1950s Black & White Photos: KEFJ			
AOI Name	**Flight Line #**	**Photo Number**	**Date**
AOIs			
Aialik Bay RS	8	BM514B0020243_ORTHO.TIF	4 July 1951
	8	BM514B0020244_ORTHO.TIF	4 July 1951
	9	BM03480100177_ORTHO.TIF	2 Aug 1950
	9	BM03480100178_ORTHO.TIF	2 Aug 1950
	9	BM03480100179_ORTHO.TIF	2 Aug 1950
Bear GLOF Source	14	BM05090030452_ORTHO.TIF	25 June 1951
	14	BM05090030453_ORTHO.TIF	25 June 1951
Northeastern Gl.	9	BM03480100173_ORTHO.TIF	2 Aug 1950
Sunrise Southwestern Gl. (was Paguna)	8	Alb_BM514B0020243_ORTHO.TIF	4 July 1951
	8	Alb_BM514B0020244_ORTHO.TIF	4 July 1951
	8	Alb_BM514B0020245_ORTHO.TIF	4 July 1951
Small AOIs & Mines Sites			
Alaska Hills Mill	5	BM514B0010069_ORTHO.TIF	4 July 1951
	5	BM514B0010068_ORTHO.TIF	4 July 1951
Beauty Bay Mine	5	BM514B0010069_ORTHO.TIF	4 July 1951
Nuka Bay Mines	5	BM514B0010068_ORTHO.TIF	4 July 1951
	5	BM514B0010069_ORTHO.TIF	4 July 1951
Nukalaska Mill Site	4	BM514B0010095_ORTHO.TIF	4 July 1951
	4	BM514B0010096_ORTHO.TIF*	4 July 1951
Rosness & Larson	5	BM514B0010069_ORTHO.TIF	4 July 1951
	5	BM514B0010068_ORTHO.TIF	4 July 1951
	5	BM514B0010067_ORTHO.TIF*	4 July 1951
Sonny Fox Mine^	5	BM514B0010066_ORHTO.TIF*	4 July 1951
	4	BM514B0010098_ORTHO.TIF*	4 July 1951
Surprise Bay^	4	BM514B0010097_ORTHO.TIF	4 July 1951
	4	BM514B0010096_ORTHO.TIF*	4 July 1951
	4	BM514B0010098_ORTHO.TIF*	4 July 1951

1980s Alaska High Altitude Photography (AHAP): KEFJ			
AOI Name	**1980s Photo Area**	**Photo Number(s)**	**Date**
Large AOIs			
Aialik Bay RS		Alb_AB584003387ROLL_331_A_ORTHO.TIF	14 August 1984
		Alb_AB584003387ROLL_330_A_ORTHO.TIF	14 August 1984
Bear GLOF Source		Alb_AB584003383ROLL_6950_A_ORTHO.TIF	12 August 1984
Northeastern Gl.		Alb_AB584003387ROLL_377_A_ORTHO.TIF	14 August 1984
Sunrise / Southwestern Gl	5	Alb_AB584003387ROLL_332_A_ORTHO.tif	14 August 1984
	5	Alb_AB584003387ROLL_331_A_ORTHO.tif	14 August 1984
	6	Alb_AB584003387ROLL_396_A_ORTHO.tif	14 August 1984
Small AOIs & Mines Sites			
Alaska Hills Mill		Alb_AB585003481ROLL_15_A_ORTHO.TIF	27 August 1985
		Alb_AB585003481ROLL_9925_A_ORTHO.TIF	27 August 1985
Beauty Bay Mine		Alb_AB585003481ROLL_15_A_ORTHO.TIF	27 August 1985
Nuka Bay Mines		Alb_AB585003481ROLL_15_A_ORTHO.TIF	27 August 1985
Nukalaska Mill Site		Alb_AB585003481ROLL_15_A_ORTHO.TIF	27 August 1985
Rosness & Larson		Alb_AB585003481ROLL_15_A_ORTHO.TIF	27 August 1985
Sonny Fox Mine^		Alb_AB585003481ROLL_9925_A_ORTHO.TIF	27 August 1985
Surprise Bay^		Alb_AB585003481ROLL_9925_A_ORTHO.TIF	27 August 1985

2005 GeoEye IKONOS Satellite: KEFJ		
AOI Name	**Photo Number(s)**	**Date**
Bear GLOF Source	po_185480_rgb_0040002.tif	8 August 2005
	po_185480_rgb_0050003.tif	8 August 2005
	po_185480_rgb_0110002.tif	10 September 2005
Northeastern Gl.	po_185480_rgb_0000005.tif	20 July 2005
	po_185480_rgb_0070000.tif	19 August 2005
	po_185480_rgb_0080000.tif	27 August 2005
Aialik Bay RS	po_185480_rgb_0000004.tif	20 July 2005
	po_185480_rgb_0050001.tif	8 August 2005
	po_185480_rgb_0060003.tif	8 August 2005
	po_185480_rgb_0100001.tif	10 September 2005
Sunrise SW Gl.	po_185480_rgb_0000003.tif	20 July 2005
	po_185480_rgb_0060003.tif	8 August 2005
Southwest and Sunrise Gl (*was Paguna Gl. Advance*)	po_185480_rgb_0000003.tif	20 July 2005
	po_185480_rgb_0010003.tif	20 July 2005
Sonny Fox mine	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0010001.tif	20 July 2005
Surprise Bay	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0010001.tif	20 July 2005
Nukalaska mill site	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0010000.tif	20 July 2005
	po_185480_rgb_0060000.tif	8 August 2005
Nuka Bay mine	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0060000.tif	8 August 2005
Beauty Bay mine	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0060000.tif	8 August 2005
Rosness and Larson	po_185480_rgb_0000001.tif	20 July 2005
Alaska Hills mine	po_185480_rgb_0000001.tif	20 July 2005
	po_185480_rgb_0060000.tif	8 August 2005

1950s Black & White Photos: LACL		
AOI Name	**Photo Number(s)**	**Date**
Lake Clark Pass	BM4H540010139	21 August 1954
	BM4H540010138	21 August 1954
	BM4H540010137	21 August 1954
	BM4H540010136	21 August 1954
	BM4H540010096	21 August 1954
	BM4G230010073	12 July 1954
	BM4G230010072	12 July 1954
	BM4G230010071	12 July 1954
	BM4G230010070	12 July 1954
	BM4G230010069	12 July 1954
	BM4G230010028	12 July 1954
	BM4G230010027	12 July 1954
	BM4G230010026	12 July 1954
	BM4G230010025	12 July 1954
	BM4G230010024	12 July 1954
	BM02220435747	02 August 1957
	BM02220435717	02 August 1957
	BM02220435716	02 August 1957
	BM02220435715	02 August 1957
	BM02220435714	02 August 1957
	BM02220435713	02 August 1957
Pickerel Lakes	HM06511614830	21 June 1955
	BM4H290010104	12 July 1954
	BM4H290010060	12 July 1954
	BM4H290010059	12 July 1954
	BM4H290010058	12 July 1954
	BM4H290010027	12 July 1954
	BM4H290010025	12 July 1954
	BM04F30010029	17 June 1954
	BM04F30010028	17 June 1954
	BM02030060740	02 August 1957
	BM02020050531	02 August 1957
	BM02020050530	02 August 1957
	BM02020050529	02 August 1957
	BCKL000300070	29 July 1954
Drift River	BM4H550010012	21 August 1954
	BM4H550010011	21 August 1954
	BM4H550010010	21 August 1954
	BM4H540010133	21 August 1954

1950s Black & White Photos: LACL		
AOI Name	**Photo Number(s)**	**Date**
	BM4H540010132	21 August 1954
	BM4H540010131	21 August 1954
	BM4H540010091	21 August 1954
	BM4H540010090	21 August 1954
	BM4G230010066	12 July 1954
	BM4G230010033	12 July 1954
	BM4G230010032	12 July 1954
	BM4G230010031	12 July 1954
Snipe lake	BM02360739817	09 July 1957
	BM02360739816	09 July 1957
	BM02360739815	09 July 1957
	BM02360739814	09 July 1957
	BM02030070850	02 August 1957
	BM02030070846	02 August 1957
	BM02030070844	02 August 1957
	BM02030060812	02 August 1957
	BM02030060811	02 August 1957
	BM02030060810	02 August 1957
	BM02030060809	02 August 1957
Tuxedni Bay	BM4H540010124	21 August 1954
	BM4H540010123	21 August 1954
	BM4H540010122	21 August 1954
	BM4H540010121	21 August 1954
	BM02220435734	02 August 1957
	BM02220435733	02 August 1957
	BM02220435732	02 August 1957
	BM02220435731	02 August 1957
	BM02220435730	02 August 1957
	BM02220435622	02 August 1957
	BM02220435621	02 August 1957
	BM02220435620	02 August 1957
Chinitna Bay	BM02220425594	12 July 1957
Upper Tazimina Lake	BM02360739830	09 July 1957
	BM02360739829	09 July 1957
	BM02020050561	02 August 1957
	BM02020050560	02 August 1957
Lachbuna Lake	BM02050131849	30 May 1957
	BM02050131848	30 May 1957

1980s Imagery: LACL		
AOI Name	**Photo Number(s)**	**Date**
Lake Clark Pass	5780026647390	25 August 1978
	5780026647389	25 August 1978
	5780026647388	25 August 1978
	5780026647329	25 August 1978
	5780026647328	25 August 1978
	5780026647327	25 August 1978
	5780026647326	25 August 1978
	5780026164833	20 June 1978
	5780026164832	20 June 1978
	5780026164831	20 June 1978
	5780026164830	20 June 1978
	5780026164829	20 June 1978
	5780026164731	20 June 1978
	5780026164730	20 June 1978
Pickerel Lakes Drift River	5780026677726	26 August 1978
	5780026677725	26 August 1978
	5780026677724	26 August 1978
	5780026677723	26 August 1978
	5780026677567	26 August 1978
	5780026677566	26 August 1978
	5780026677565	26 August 1978
	5780026677564	26 August 1978
	5780026647374	25 August 1978
	5780026647373	25 August 1978
	5780026647372	25 August 1978
	5780026647371	25 August 1978
	5780026647370	25 August 1978
	5780026164816	20 June 1978
	5780026164815	20 June 1978
	5780026164814	20 June 1978
	5780026164813	20 June 1978
	5780026164812	20 June 1978
Snipe lake	5780026164799	20 June 1978
	5780026164798	20 June 1978
	5780026164797	20 June 1978
	5780026164747	20 June 1978
	5780026164746	20 June 1978

1980s Imagery: LACL		
AOI Name	**Photo Number(s)**	**Date**
	5780026164745	20 June 1978
Tuxedni Bay	5780026677777	26 August 1978
	5780026677776	26 August 1978
	5780026677776	26 August 1978
	5780026677775	26 August 1978
	5780026677774	26 August 1978
	5780026677542	26 August 1978
	5780026677541	26 August 1978
	5780026677540	26 August 1978
Chinitna Bay	5780026677711	26 August 1978
	5780026677710	26 August 1978
	5780026677709	26 August 1978
Upper Tazimina Lake	5780026677753	26 August 1978
	5780026677752	26 August 1978
Lachbuna Lake	5780026164801	20 June 1978
	5780026164800	20 June 1978
	5780026164799	20 June 1978

IKONOS Imagery: LACL.		
AOI Name	**Photo Number(s)**	**Date**
Lake Clark Pass	Po_501298_bgrn_0000604.tif	2006-2010
	Po_501298_bgrn_0000704.tif	2006-2010
Pickerel Lakes	Po_501300_bgrn_0000104.tif	2006-2010
	Po_501300_bgrn_0000103.tif	2006-2010
	Po_501300_bgrn_0000004.tif	2006-2010
	Po_501300_bgrn_0000003.tif	2006-2010
Drift River	Po_501298_bgrn_0000706.tif	2006-2010
	Po_501298_bgrn_0000705.tif	2006-2010
	Po_501298_bgrn_0000605.tif	2006-2010
	Po_501298_bgrn_0000606.tif	2006-2010
Snipe lake	Po_501298_bgrn_0000105.tif	2006-2010
	Po_501298_bgrn_0000005.tif	2006-2010
Tuxedni Bay	Po_501300_bgrn_0000802.tif	2006-2010
	Po_501300_bgrn_0000801.tif	2006-2010
	Po_501300_bgrn_0000702.tif	2006-2010
	Po_501300_bgrn_0000701.tif	2006-2010
Upper Tazimina Lake	Po_501300_bgrn_0000604.tif	2006-2010
	Po_501300_bgrn_0000704.tif	2006-2010
Lachbuna Lake	Po_501298_bgrn_0000106.tif	2006-2010
	Po_501298_bgrn_0000206.tif	2006-2010
	Po_501300_bgrn_0000300.tif	2006-2010
	Po_501300_bgrn_0000400.tif	2006-2010

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