Orthorectification and Automation

of

Kenai Fjords Park and Preserve

Landcover Mapping

Pacific Northwest CESU Task Agreement #J8W07070018

GeoSpatialServices

Saint Mary's University
OF MINNESOTA

Kenai Fjords Orthorectification and Digital Conversion

Background:

The National Park Service's Alaska Landcover Mapping Program is funded through the inventory portion of the NPS Inventory and Monitoring Program (I&M) and has as its goal the provision of basic vegetation information on a park-wide basis for all national parks in Alaska. Landcover mapping is intended to provide data that are useful for the design and implementation of other I&M Programs as well as facilitate general resource management decision making within parks.

The NPS landcover mapping program began with a Kenai Fjords National Park (KEFJ) landcover mapping project under separate agreement that provided for manual photo interpretation of landcover types within the Park using color infrared (CIR) photography. This photo interpretation was captured as delineations on acetate mylars that overlay on 1:36000 or 1:40000 scale CIR photography.

NPS recently purchased high-resolution (IKONOS) orthoimage products for KEFJ. These products are the base cartographic reference for the Park and can be used to georeference other image and spatial datasets to a common base.

The purpose of this project was to create digital landcover data with the highest possible accuracy for Kenai Fjords National Park. The projected utilized the best available base data and a rectification process selected from a variety of different approaches that were assessed in a pilot project.

Study Area and Mapping Program:

Kenai Fjords National Park and Preserve is located approximately 110 miles south of Anchorage on the southeastern Kenai Peninsula near the community of Seward (Figure 1). The Gulf of Alaska forms the east coast boundary of the park.   Seward the "Gateway to Kenai Fjords National Park" is accessible by car, railroad, boat, or air. The park gets its name from the steep glacier carved valleys filled with ocean water. Kenai Fjords National Park covers approximately 2 million acres of Kenai Peninsula and contains almost 65% of the Harding Icefield. The Park is covered with spruce and birch forests, hundreds of lakes, and includes a wide variety of mountains and glaciers.

Figure 1: Location of Kenai Fjords Park and Preserve
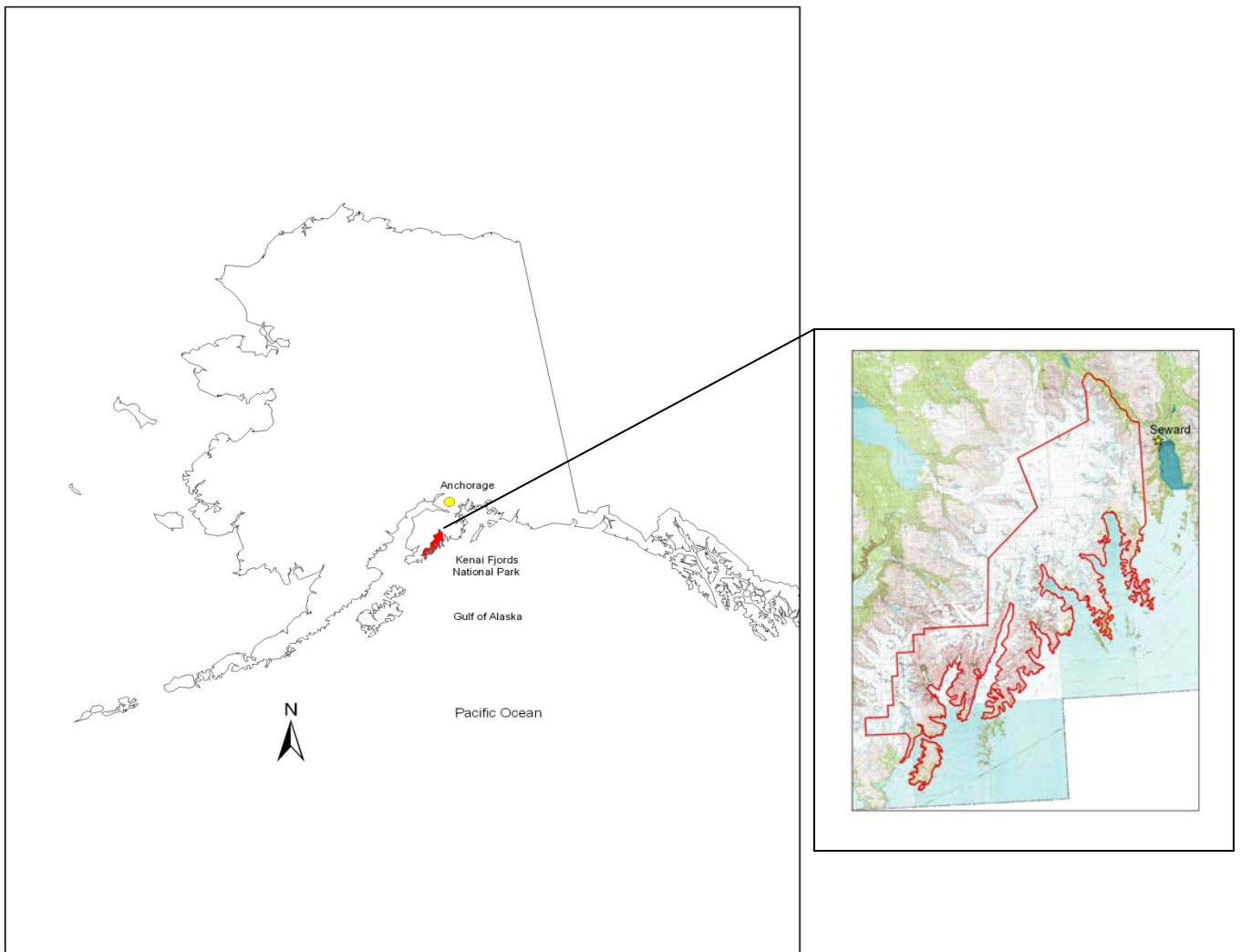
The Inventory and Monitoring Program of NPS is designed to provide reliable and consistent information for assessing status and trends in the condition of Alaska's National Park ecosystems including Kenai Fjords. Vegetation mapping is conducted under the inventory portion of the program in order to provide basic information, readily useful for making resource management decisions, and to collect data that can be aggregated on a service-wide level for designing monitoring programs.

Photos obtained by the NPS for landcover mapping in Kenai Fjords were from two different years and were flown by two different groups. The 2003 aerial photos were taken by GPS Aerial Services, Inc. The camera type was a Wild RC30 aerial camera equipped with a Wild Universal Aviogon 4-S lens (calibrated focal length of 153.682 mm). The 2004 aerial photos were taken by the Alaska BLM and used the camera Wild RC10 equipped with a Wild Universal Aviogon II lens (calibrated focal length of 153.276 mm). The products of these missions were a series of 1:36,000 and 1:40,000 scale, color infra-red aerial photographs for the Park. The photographs were flown so as to provide 60% overlap between each frame allowing for stereoscopic viewing and detailed image interpretation.

Aerial photo interpreters from The Alaska Natural Heritage Program were contracted by NPS to complete landcover mapping on these photographs through the use of traditional photo interpretation techniques. The results of their work were a series of 123 individual aerial photograph frames with acetate overlays on which landcover polygons were delineated and classified using a fine point, Rapidograph drafting pen and India Ink.

Digital Conversion Methodology:

Digital conversion refers to the process by which the hardcopy aerial photographs and ink delineations of landcover polygons on acetate overlays were transformed into digital images and digital vector data within a Geographic Information System (GIS).

Pilot Project:

The process to achieve the best quality digital conversion was determined by examining the results of a series of tests using the digital image and acetate overlays of photo L5-15. The first two tests used standard procedures of orthorectification with two different sources of Digital Elevation Model (DEM) supplied by the NPS (NED DEM and IKONOS DEM). No other adjustments were made to the final orthorectified photo and polygon data in these tests.

In order to try and improve the match between the orthorectified landcover polygons and the IKONOS base imagery, a second test was conducted using the orthorectified, vectorized polygons from test one and a spatially adjustment process in ArcGIS. This process is sometimes called "rubber sheeting" and involves stretching and moving spatial data to achieve an improved spatial orientation over existing, accurate spatial layers.

 Yet another test eliminated the use of orthorectification all together from the image adjustment process and relied on simply georeferencing of the digital images in ArcGIS with use of the georeferencing tools. No terrain or elevation adjustment was incorporated in this test.

The final test involved having a photo interpreter transfer delineated landcover polygons from the acetate overlays to hardcopy mylar plot of the appropriate IKONOS image made at the same scale as the acetate overlay. The transfer process was completed using a mirror stereoscope with the photo on one side and the mylar plot on the other side. Once the data was transferred, the mylar plot was scanned and georeferenced. The thought with this final procedure was that if the line work was delineated on an existing orthorectified base (IKONOS imagery) then there would be no need for the orthorectification step using DEM's thus eliminating issues arising with DEM coverage and quality.

The results of these tests were shared with the NPS and the best outcome with regard to accuracy and cost was determined to be standard processing with the best base imagery and DEM available. Optimum results came from the use of IKONOS base imagery for georeferencing and IKONOS DEM for orthorectification. In all test cases using this approach, positional accuracy of the final landcover data was within the National Map Accuracy Standard (NMAS) for 1:63,360 scale maps; +/-32 meters.

The standard process had five main steps: photo and acetate scanning; georeferencing and orthorectification of scans using IKONOS DEM; raster to vector conversion of delineated polygons (from scanned acetates); polygon attribution; and edge matching and quality control.

Photo and Acetate Scanning:

NPS provided 123 photos with associated acetate overlays for digital conversion. Upon receipt of these hardcopy products, the photos were inventoried and logged into a project management database in order to ensure that all materials had been received. The photos were then separated into two sub-project areas (2003 and 2004) based on the year in which the photos were flown and the scale of the final product.

Once sub-divided, the acetate overlays, which had been attached to the photos using drafting tape, were physically separated from the aerial photographs for scanning. Each photo and acetate pair was scanned using a desktop Epson Expression 1640 XL flatbed color image scanner to the user defined specifications listed below. During the scanning process, care was taken to ensure that all fiducial marks and overlay tie points were visible on each scan as they were required for later orthorectification and image processing. The scans were then saved using the file naming convention of <photo#>P.tif for photographs and <photo#>L.tif for polygon linework from the acetate overlays.

Scan Specifications - Photography:

- Scan resolution: 1200 dpi (21 microns)
- Pixel Depth: 16 bit
- File Format: TIFF
- Re-sampling Method :   Nearest Neighbor
- Multi-band (red-green-blue)

Scan Specifications - Acetate Overlay:

- Scan resolution: 1200 dpi (21 microns)
- Pixel Depth: 1 bit
- File Format: TIFF
- Single band black and white

Georeferencing and Orthorectification:

Georeferencing or photogrammetric control is the process by which known ground control points are used to provide geographic reference to a scanned aerial image and/or graphic. Orthorectification is the process by which a digital elevation model and a camera calibration report are used to correct image displacement caused by terrain variation and camera lens aberrations. On the Kenai Fjords project, these processes were used to create georeferenced aerial photography for use as a backdrop GIS product and to create georeferenced, terrain rectified raster versions of the delineated acetate scans that could be further processed into digital landcover layer. The software package used for georeferencing and orthorectification on this project was OrthoMapper rev. 3.18 from Image Processing Software Inc.

The aerial photography and associated acetate overlays for the Kenai Fjords project were georeferenced using four different data sources. For much of the park area (approximately 90%), NPS provided IKONOS imagery which was used for the selection of high quality control points (Figure 2). For areas of the park where this imagery was not available, ground control points were selected from DOQQ's, 1993 Coastal black and white photos in MrSID format (Figure 3) and/or digital copies of the appropriate USGS 1:63,360 digital raster graphic (DRG) quadrangles for Alaska. OrthoMapper rev. 3.18 software does not support the use of images in MrSID format. As a result, the 1993 coastal black and white imagery needed

to be converted into TIFF format using ArcMap 9.2. This added an extra processing step for areas where the coastal black and white photography was the only imagery available for georeferencing.

In order to provide the best possible match, a minimum of 5 georeference control points were required for every photo. However, in most cases between 15 and 20 points were used in order to improve the accuracy of the referencing process. On photos where much of the image was covered with ice and snow, it was often difficult to find an adequate number of quality control points.

For every photo, a text file was generated in order to document the approximate error of the georeferencing process. Typical Root Mean Square (RMS) error for areas georeferenced to the IKONOS imagery was between 2 and 10 meters. Areas that were georeferenced using the USGS quadrangles typically had RMS errors of between 15 and 30. Areas that were georeferenced using the 1993 coastal black and white imagery proved to have the highest RMS errors (sometimes exceeding 75 meters). This was completely due to the poor spatial reference of the original digital imagery. This issue was discussed with Park Service staff from the Alaska Region Inventory and Monitoring group during a meeting on November 01, 2007 and it was concluded that there was no other choice but to use the 1993 coastal imagery for georeferencing in areas where no other digital source existed. In these areas, extra time was taken during the raster to vector conversion process in order to match the landcover to the base imagery.

All aerial photographs and acetate overlays were georeferenced to North American Datum of 1983 (NAD83-CORS96 or CORS94) and as further specified below:

```
PROJCS["NAD_1983_UTM_Zone_8N",
GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137,298.257222101]],
PRIMEM["Greenwich",0],
UNIT["Degree",0.017453292519943295]],
PROJECTION["Transverse_Mercator"],
PARAMETER["False_Easting",500000],
PARAMETER["False_Northing",0],
PARAMETER["Central_Meridian",-135],
PARAMETER["Scale_Factor",0.9996],
PARAMETER["Latitude_Of_Origin",0]
UNIT["Meter",1]]
```

Figure 2: NPS Supplied IKONOS Imagery Coverage
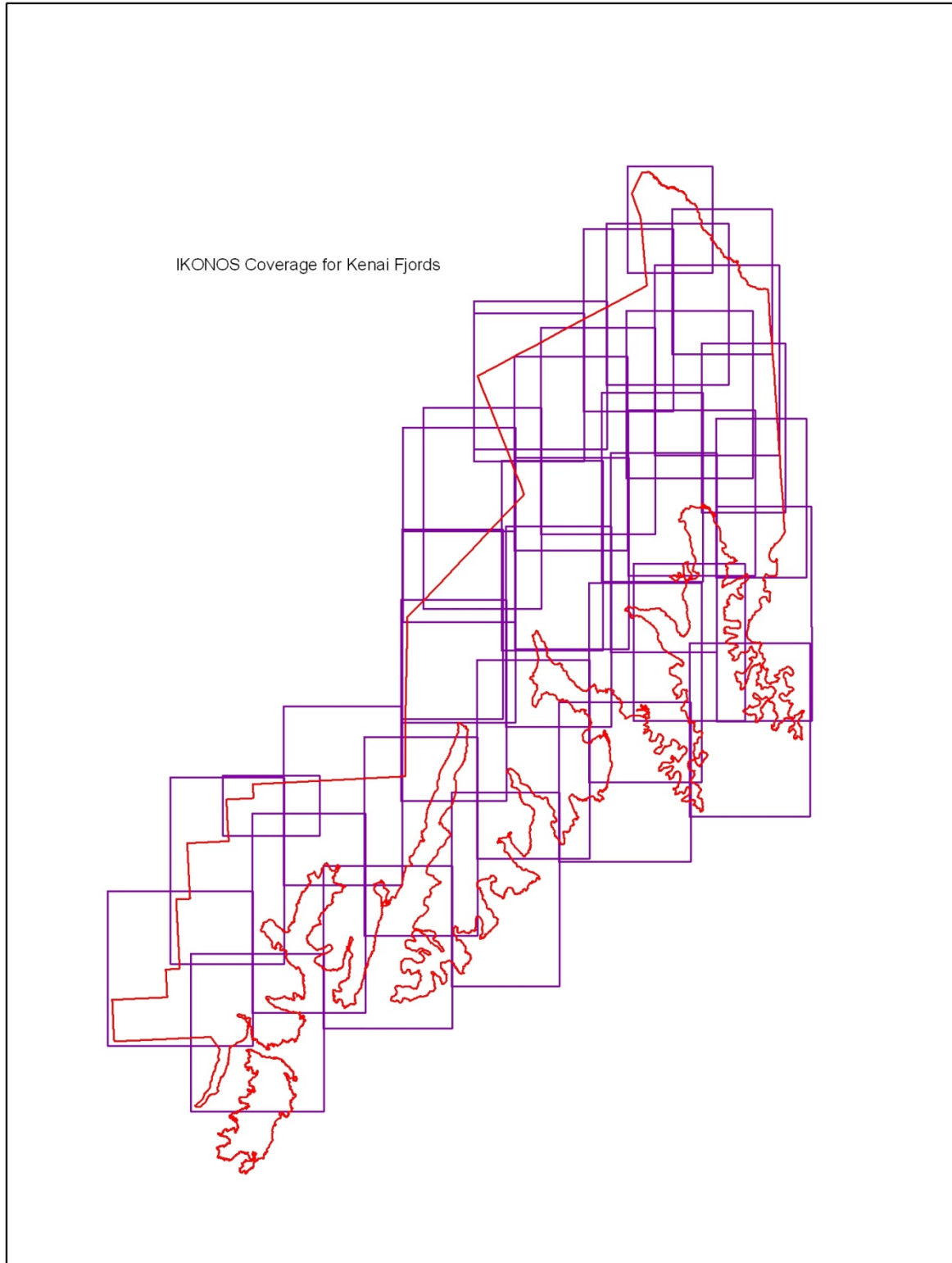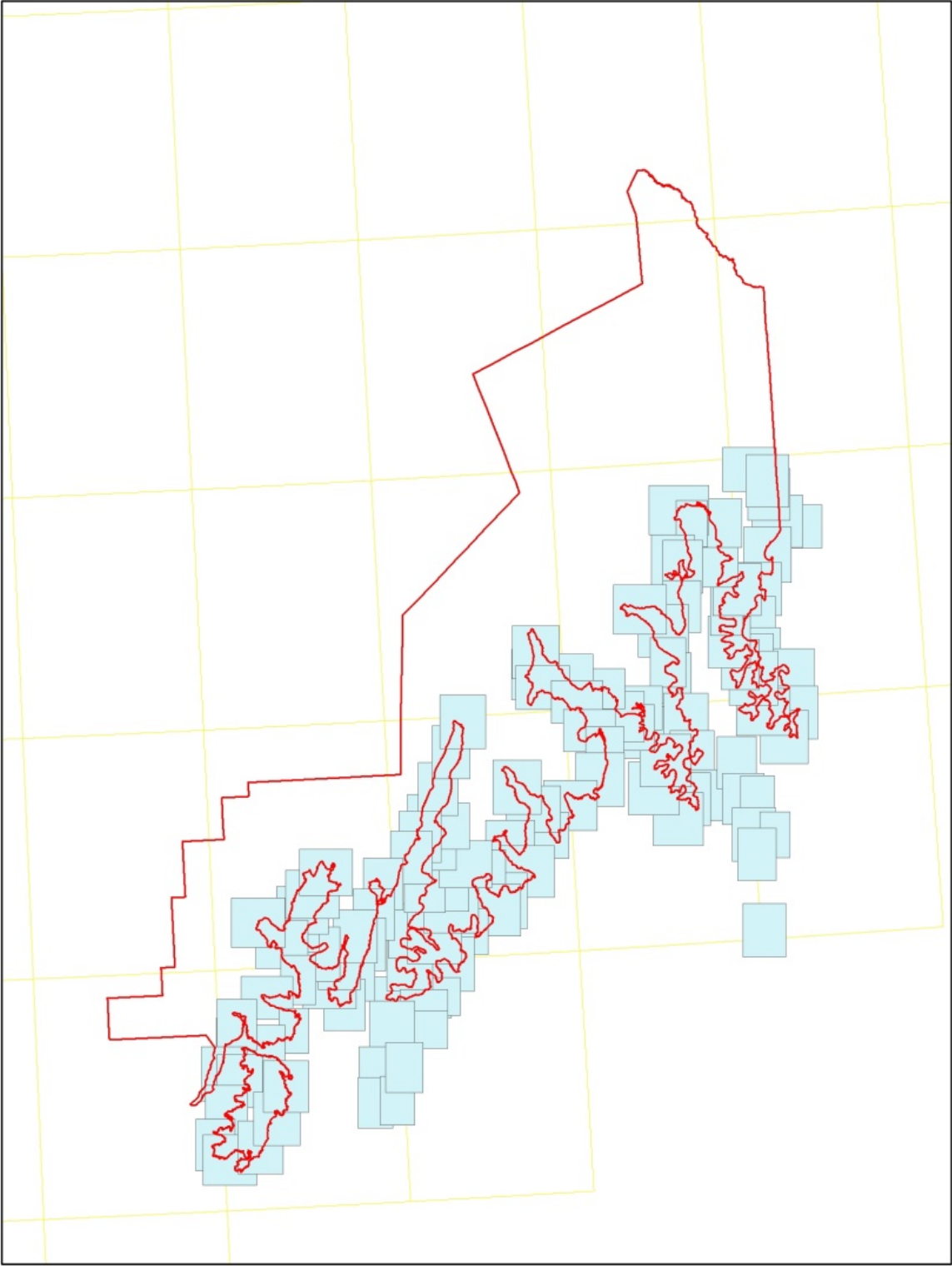

IKONOS Coverage for Kenai Fjords

Figure 3: Park Boundary, Quads, and 1993 Coastal Black and White Imagery Index

Orthorectification of the scanned products for Kenai Fjords was completed using three different Digital Elevation Models. For areas where there was IKONOS imagery provided by NPS, there was also an IKONOS DEM that was built for the orthorectification of the IKONOS imagery referenced above. These IKONOS DEM's came in separate pieces that when used independently created a "no data" strip along the edges where the DEM's overlapped. When used in the native form, this no data strip on the DEM carried over to the orthorectified photos and overlays and erased large amounts of imagery in these areas. As a result, processing of the DEM's in their native GRID format was needed to merge the IKONOS DEM's and eliminate the problem in the overlap regions.

Unfortunately, the IKONOS DEM did not entirely cover all of the areas of the park for which there were photos and acetate overlays that required orthorectification (Figure 4.). To resolve this issue, a composite DEM was created by merging NASA Shuttle Radar Topography Mission (SRTM) DEM data with existing IKONOS DEM data. The SRTM DEM is a 30 meter resolution elevation product derived from data captured during an 11 day space shuttle mission in 1999. The SRTM DEM and the IKONOS DEM were merged together with the priority elevation data coming from the IKONOS DEM. To further resolve missing DEM coverage issues and known holes in the SRTM coverage, NED DEM was also merged into this composite coverage to provide elevation values in areas that were blank from the IKONOS and SRTM. All GRID calculations for construction of this composite DEM were conducted in ArcMap 9.2 with the Spatial Analyst extension. These DEM files were converted to TIFF format, projected to NAD83 (using the projection definition above) and then converted to a .dem format for use with OrthoMapper.

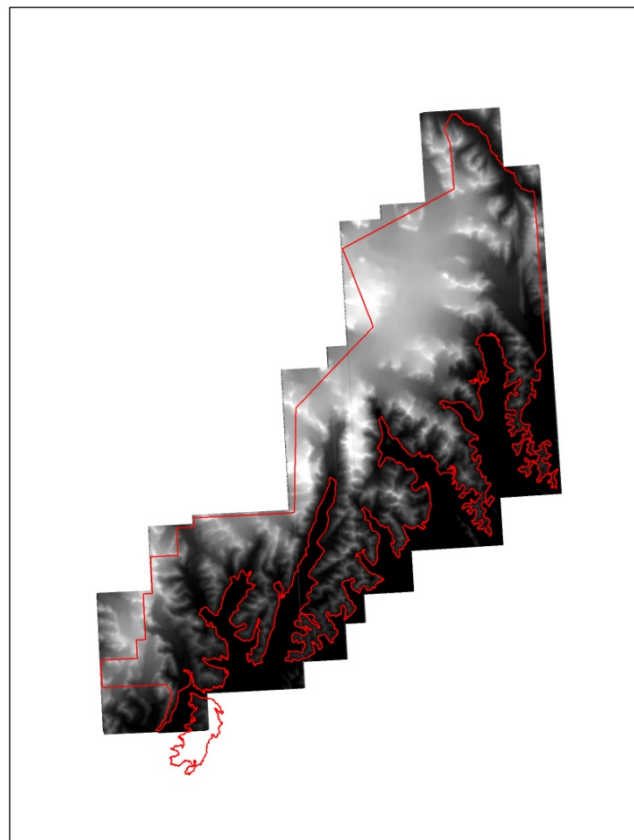Figure 4: Merged Coverage of NPS Supplied IKONOS DEM
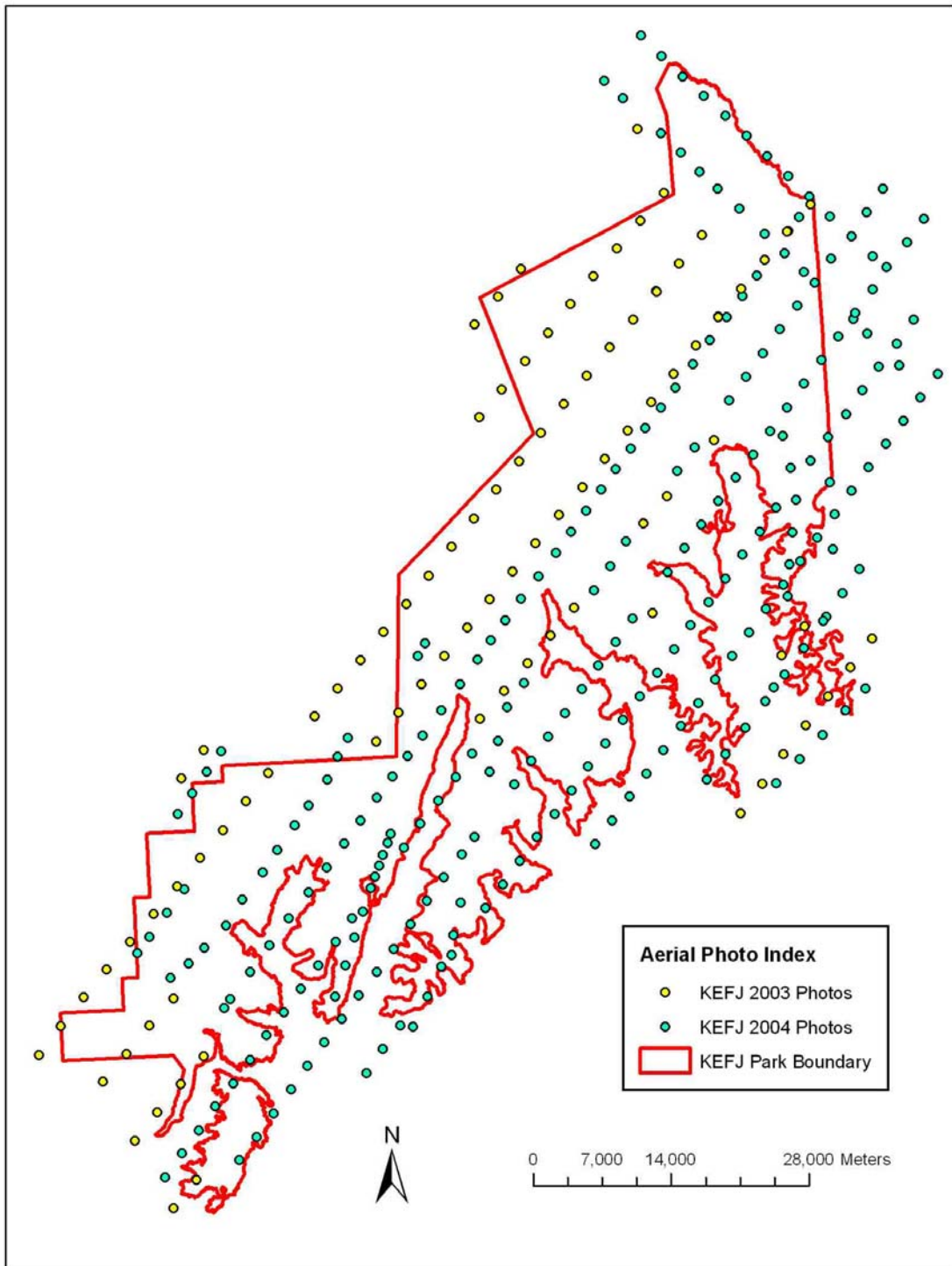
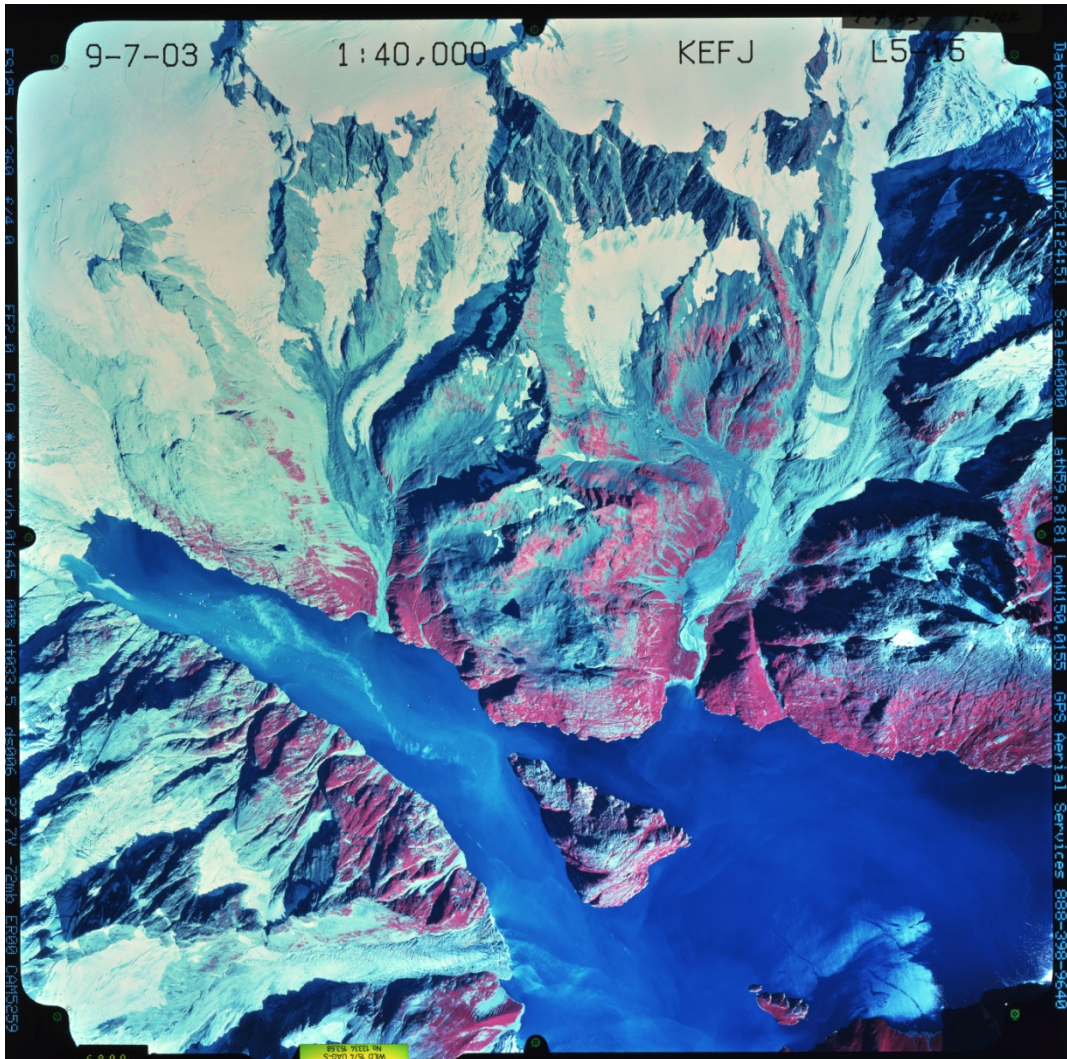Figure 5: Photo Index

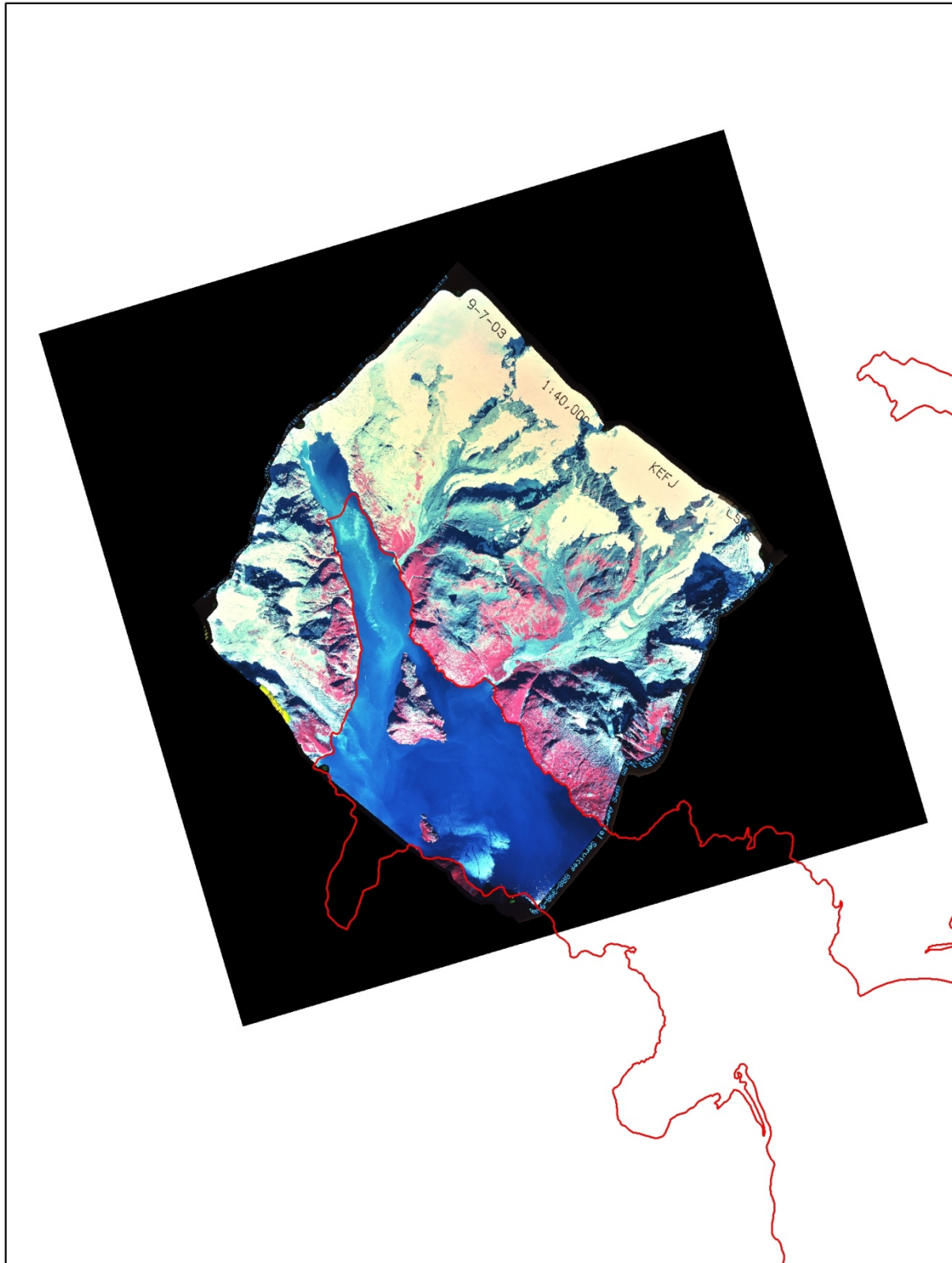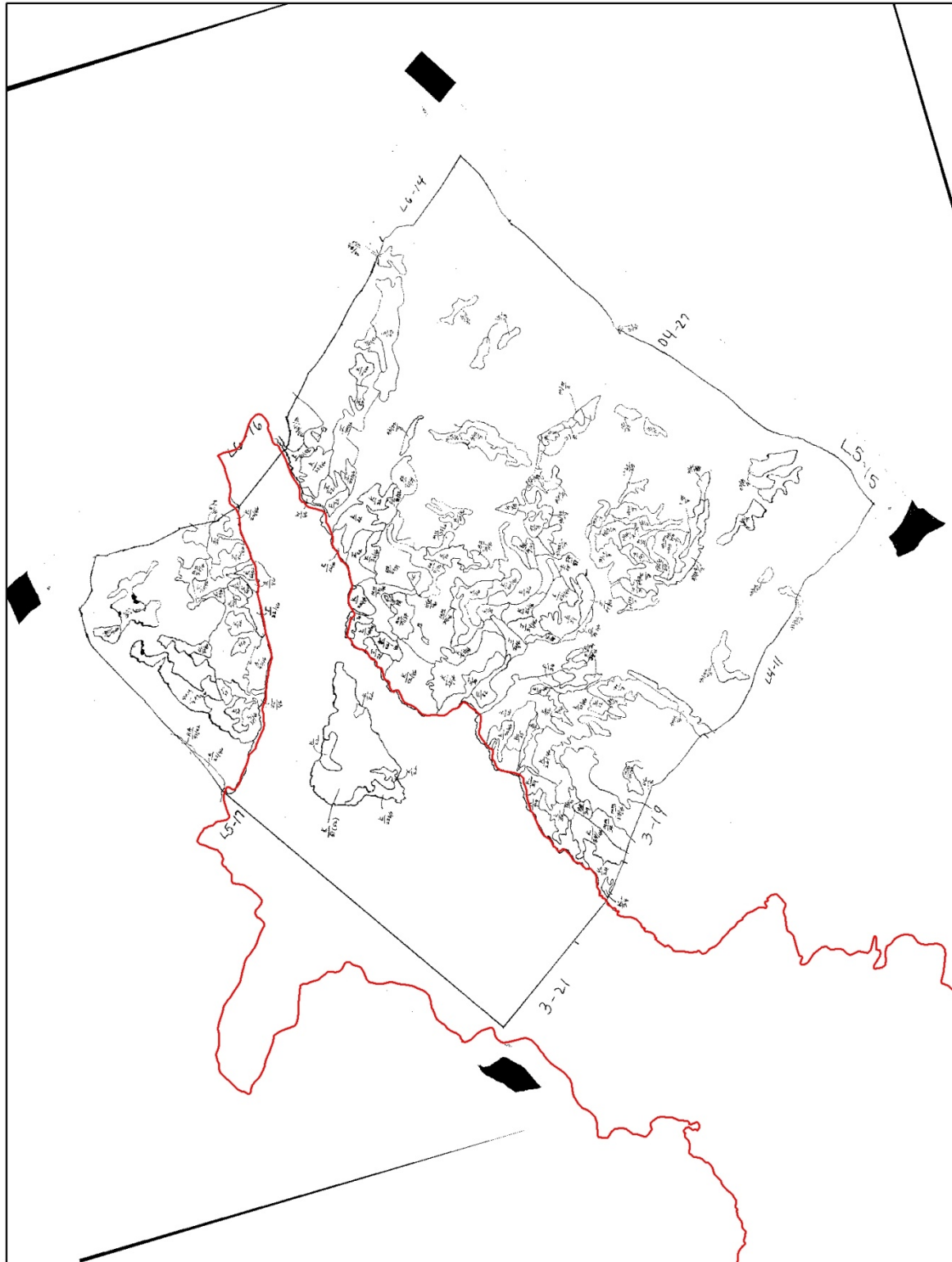Figure 6: Sample Scanned Photo

Figure 7: Sample Orthorectified Photo

Figure 8: Orthorectified Acetate Overlay

Raster to Vector Conversion:

The next step in the digital conversion process was to take the georeferenced and orthorectified acetate overlays and convert them from raster to vector format. This step was required so that the NPS landcover data could be represented as polygon data in ArcGIS as opposed to grid cells. This conversion was accomplished using the ArcScan extension in ArcMap. ArcScan is a suite of software tools that provides raster-to-vector conversion and raster editing capabilities in ArcGIS. ArcScan includes capabilities to perform interactive raster editing, raster geometric correction and noise removal, and interactive raster-to-vector conversion.

The most time intensive task in the vector conversion process is "noise cleanup". Noise refers to the fact that the scanned acetate overlays typically contain more information than just the polygon boundaries which will form the final vector product. These artifacts include such things as: hand written polygon attributes, arrows, dashed lines, and tag lines. All of these features must be edited and removed from the raster image prior to vector conversion so that only the actual polygon boundaries are vectorized. Noise cleanup is basically a manual process in which every part of the scan must be reviewed and, if necessary edited, to ensure that only valid polygon boundaries remain.

Once the scans have been cleaned, vectorization is an automated process that is handled by the ArcScan software. The user is required to set certain parameters in order to achieve the best vector output. The parameter settings that were used on the Kenai Fjords project are shown in Figure 10 below. These settings have been determined to provide the most consistent raster to vector conversion through various conversion projects.

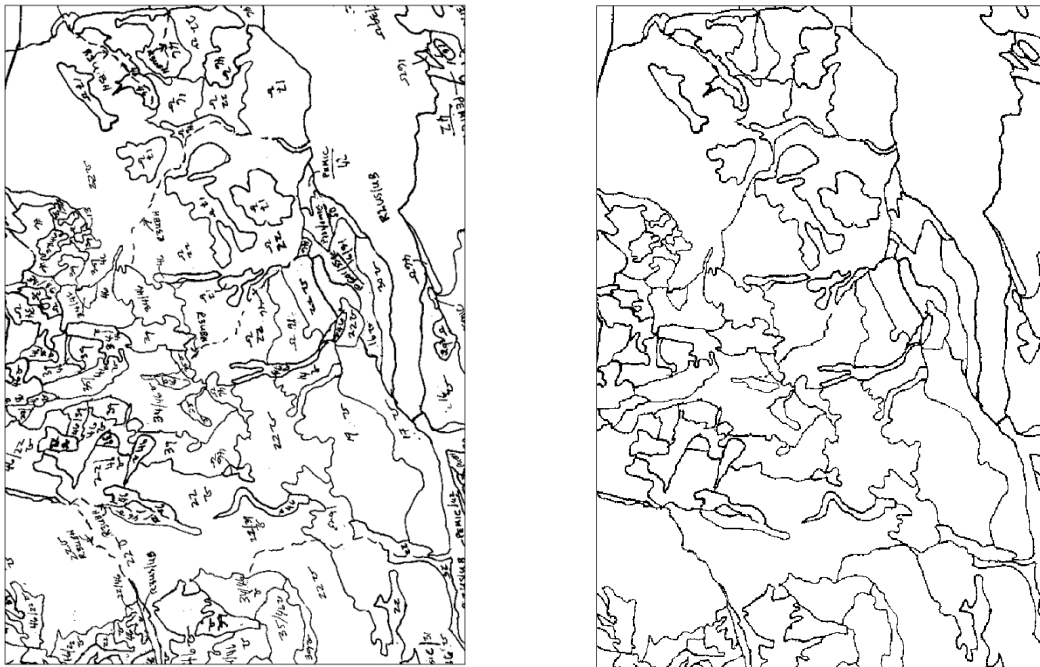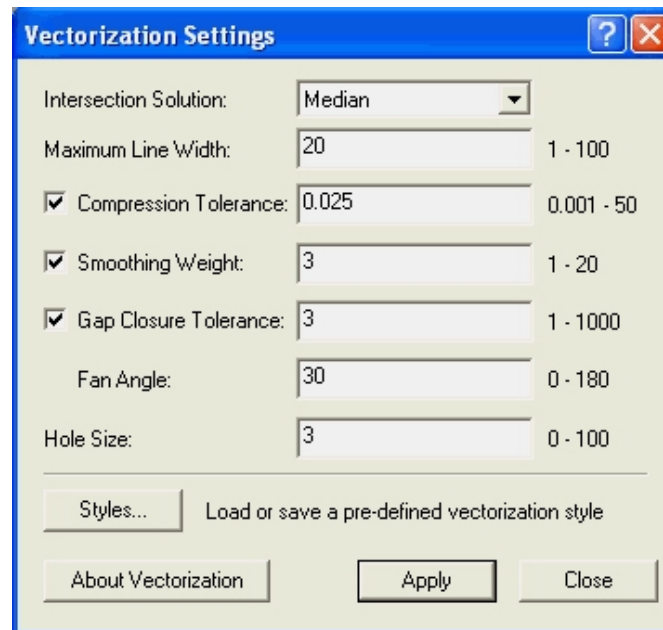Figure 9: Dirty vs. Cleaned Acetate Overlay

Figure 10: ArcScan Vectorization Settings

Attribution:

Attribution refers to the process of attaching a descriptive identifier to vectorized polygons so that the data have meaning to an end user. Attributes are typically stored in a database table that is linked directly to the feature geometry. Traditionally, polygons are attributed by opening the cleaned vectorized line work on top of the original orthorectified overlay, pointing at the polygon on the screen to select that feature, opening the database table and typing in the polygon attribute as it is displayed from the ortho overlay on the screen. This is primarily a manual process in which editors interact with ArcMap in order to type in each and every polygon attribute.

Four fields were created in each table (Figure 11).

NPS – National Park Service codes. Code description (Figure 12)

ECO_SYS – Ecological systems codes. Code description (Figure 13)

PI_CHECK – Codes for unknown and questioned polygons. Used by NPS to query and verify codes

OLD_GROWTH – a YES in this field means old growth is present in this polygon

PI_CHECK is a field created to assist the NPS in verifying questions/issues that came up during the attribution process. For example, water versus glacier can be problematic to resolve or simply attributes were missing. This field was broken down into specific codes that could be queried and handled by specific NPS specialists. Valid codes were as follows:

0 – Two attributes in one polygon or some issue that needed to be addressed by the photo interpreter

111 – Illegible codes or missing codes

222 – Incomplete polygon. NPS provided GSS with permission to conduct photo interpretation to resolve these. If GSS was unable to fix the "hole" in the polygon these polygons were marked with a 0 for a review by NPS photo interpreters.

333 – Glacier area that was missing codes

444 – Water area that was missing codes

Figure 11: Example of Landcover Geodatabase Fields

NPS	ECO_SYS	PI_CHECK	OLD_GROWTH
46	J	<Null>	<Null>
41	C	<Null>	YES
3	C	<Null>	YES
41	C	<Null>	YES
3	C	<Null>	YES
3	C	<Null>	YES
1	A	<Null>	YES
1	A	<Null>	YES
19	L	<Null>	<Null>
<Null>	<Null>	111	<Null>
24	F	<Null>	<Null>
46	GG	<Null>	<Null>
42	BB	<Null>	<Null>
36	CC	<Null>	<Null>
26	J	<Null>	<Null>
<Null>	<Null>	333	<Null>
48/46	FF	<Null>	<Null>
26/46	K	<Null>	<Null>
21	L	<Null>	<Null>
26	J	<Null>	<Null>
2	D	<Null>	<Null>
37/46	MM	<Null>	<Null>
4	A	<Null>	YES
<Null>	<Null>	0	<Null>
<Null>	<Null>	444	<Null>

Figure 12: Landcover Codes

Kenai Fjords Landcover classes draft - October 2006

Lifeform	Mapping Code	Landcover Class	Canopy Cover (%)	Comments
Needleleaf Forest	1	Closed Spruce	60-100%	
	2	Closed Hemlock	60-100%	
	3	Closed Spruce-Hemlock	60-100%	
	4	Open Spruce	25-59%	
	5	Open Hemlock	25-59%	
	41	Open Spruce-Hemlock	25-59%	
	7	Woodland Spruce (7/39 = 53)	10-24%	
	8	Woodland Spruce/Alder	10-24%	
	49	Woodland Spruce/Alder-Willow	10-24%	
	53	Woodland Spruce/Herbaceous	10-24%	
	10	Woodland Spruce-Hemlock	10-24%	
	11	Woodland Hemlock	10-24%	
	54	Krumholz	10-24%	
	12	Dead forest (standing dead)	>10% trees	
Broadleaf Forest	13	Closed Cottonwood	60-100%	
	14	Open Cottonwood	25-59%	
	15	Woodland Cottonwood	10-24%	
Mixed Forest	16	Closed Spruce-Cottonwood	60-100%	
	17	Open Spruce-Cottonwood	25-59%	
	18	Woodland Spruce-Cottonwood	10-24%	
Peatland	19	Hemlock/ Spruce Peatland	10-24%	
	20	Open Low Shrub Peatland	10-100%	
	21	Herbaceous Peatland (also listed under Herbaceous)	>25% veg	
Closed Tall Shrub	22	Closed Tall Alder	75-100%	
	23	Closed Tall Willow	75-100%	
	24	Closed Tall Alder-Willow	75-100%	
	25	Closed Alder-Salmonberry	75-100%	
	55	Closed Tall Salmonberry	75-100%	
	26	Closed Alder-Herbaceous Mosaic	75-100%	
Open Tall Shrub	27	Open Tall Alder-Willow	25-74%	
	28	Open Tall Willow	25-74%	
	57	Open Tall Alder	25-74%	
Closed Low Shrub	29	Closed Low Willow	75-100%	
	30	Closed Low Alder-Willow	75-100%	
	31	Closed Low Salmonberry	75-100%	
	40	Closed Low Alder	75-100%	
Open Low Shrub	32	Open Low Willow	25-74%	
	33	Open Low Willow-Herbaceous	25-74%	
	52	Open Low Alder	25-74%	
	34	Open Low Alder-Willow	25-74%	
	35	Open Low Salmonberry	25-74%	
	56	Open Low Shrub	25-74%	
Dwarf	36	Dwarf Shrub	25-100%	
	37	Dwarf Shrub - Herbaceous Mosaic (inc. Nephrophyllidium crista-galli)	25-100%	
Herbaceous	38	Dry Herbaceous	25-100%	
	39	Mesic Herbaceous	25-100%	
	42	Wet Herbaceous	10-25% veg	
	43	Herbaceous Marsh	25-100%	includes former 50 (FW marsh and 43 Tidal Marsh)
	21	Herbaceous Peatland (also listed under Peatland)	25-100%	
	44	Intertidal - Puccinellia, Glaux	10-25% veg	
Aquatic/Non-vascular	45	Freshwater Aquatic Herbaceous	25-100%	
	48	Moss/Lichen	25-100%	
Sparse/bare	51	Sparsely vegetated	10-25% veg	
	46	Unvegetated	<10% veg	
	47	Sparsely vegetatated/Unvegetated Mosaic	<10% veg in clumps	
Other	100	Human disturbance	25-100%	
	Pd	Pond		
	Lk	Lake		
	Rv	River (only those large enough to draw a polygon)		
	Ω	(upside down Omega) - Old Growth	DIDN'T USE 6 AND 9 -EASILY CONFUSED	

Figure 13: Ecological System Codes

System code	System
A	Sitka Spruce
B	Treeline Spruce or Hemlock
C	Sitka Spruce-Mt. Hemlock,
D	Mountain hemlock
E	Floodplains
F	Glacial Outwash
RR	Coastal Moraine
G	Alluvial Fan
J	Tall Shrub-disturbance prone [formerly Avalanche]
K	Tall Shrub (recently deglaciated)
L	Sloping Peatland (moderate to steep)
N	Flat Peatland
O	Freshwater Marsh
P	Aquatic Bed
R	Talus Slopes and Colluvial Fans
S	Coastal Marsh and Mudflat (shared with Cook Inlet)
T	Cobble Beaches and Beach Meadows
V	Sandy Beaches and Beach Meadows
W	Seaside Cliffs
X	Steep Bedrock
Z	Subalpine Tall Shrub
AA	Active Alpine Talus Slopes (partially vegetated)
BB	Alpine Herbaceous Meadow
MM	Alpine Herbaceous-Dwarf Shrub
CC	Alpine Dwarf Shrub
PP	Alpine Sparse Dwarf Shrub
SS	Alpine Riparian (not floodplain)
DD	Alpine Flood Plain
TT	Alpine Alluvial Fan
EE	Graminoid High Alpine
FF	Steep Bedrock, Rocky Ridges, and Cliffs
GG	Unvegetated Bedrock
JJ	Unvegetated Talus
KK	Snow and Ice

Edgematching and Quality Control:

As mentioned above, the landcover polygons were delineated on 123 individual photos for this project. In order to create a seamless final polygon layer covering the entire park, the polygon data had to be "stitched" together through the process of edgematching. This process involved having the editor review all of the seams where the data from one photo joined with another photo in order to ensure that polygons matched geometrically and shared the same attribute. Any artificial neat lines that were used to close polygons on individual photographs were removed at this point and polygon edges were reshaped and snapped as necessary to achieve geometric coincidence with the adjacent data. Individual photos were first edgematched in blocks of around 12; approximately equivalent to the extent of a USGS 1:63,360 quadrangle. These blocks of 12 photos were then edgematched together to create the seamless park wide dataset. The orthorectified photos were used as a background layer to aid in edge match decision making.

Quality control of the final product was managed in several different ways. During the orthorectification phase, the amount of error associated with the selection of individual georeferencing control points was monitored and points that had too much error were eliminated from the final rectification. The use of the merged DEM was limited to only those photos that extended beyond the boundaries of the IKONOS DEM. An average of 15 to 20 control points were chosen per photo in order to ensure that spatial correlation was the best possible. Final georeferencing and orthorectification generally had an average RMS error of less than 10 meters.

With regard to the raster to vector conversion phase of the project, final delineations were checked multiple times against three different sources. Initially, polygon boundaries were check by overlaying them with the original orthorectified overlay. This was to ensure that all of the line work was present and matched the original data. Next, the delineations were checked against the pre-existing land cover layer in order to identify line work that had been edited or changed by NPS during review of the original product. Finally, the delineated boundaries were superimposed on the IKONOS imagery provide by NPS in order to ensure concurrence between the land cover layer and the photo base that most users will be viewing it on. An ArcGIS topology check was also run on the final dataset to ensure topological integrity. The topology rules that were enforced during this check included: must not have gaps and must not have overlaps.

Quality control of the attribution phase of the project was managed in two ways. First, approximately 20% of the polygons across the study were randomly chosen and reviewed against the scanned acetate by a separate editor as further verification of attribute accuracy. Finally, attribute codes were check for legitimacy by searching the entire database for values that did not match a master list of codes provided by NPS. This was completed by running a series of SQL queries against the final database.

Upon completion of internal quality control, the landcover geodatabase plus the orthorectified imagery and the scanned and georeferenced mylar overlays were sent to the NPS for checking. This review included an evaluation of original and new delineated boundaries and a validation of attribute coding. During the checking process, NPS specialists added 5 new fields in the attribute table. They were as follows:

Proofed_NPS - NPS codes proofed by the NPS

Reminder - Notes about the polygon edits, such as, where to split the polygon, did the NPS supply a screen grab, was our attribute call good, is the polygon out of the park, etc.

Proofed_ECO - Ecological system code proofed by the NPS

Proofed_OG – Old growth codes proofed by the NPS

UNIK – Used to retain the polygon object ids. Edits to the polygon features changes the OBJECTID
      field. The UNIK field did not change.

The NPS did not change attributes in any of the original fields (Figure 11). For the purposes of tracking edits, the field SMU_FIX was added. To this field, codes were added (DONE, edits completed; UKN, there was still a question; or YALIK, questions about the Yalik area) to let the NPS know where issues had been addressed or if there were still questions about what the NPS wanted changed. To assist in making decisions NPS supplied, in several cases, shapefiles and/or screen grabs of the polygons in need of edits. Editing instructions for polygon issues were found in the reminder field. After the corrections were made a final topology check was run on the entire feature class. Once complete, the final data layer was returned to NPS for their use.

Final Products:

Final products for the Kenai Fjords orthorectification project included the following:

1. 123 scanned aerial photos and acetate overlays as per the specifications listed above.
2. Orthorectified aerial photos delivered as 8 bit pixel depth, 1 meter pixel resolution, full color TIFF format files. These files all included OGC compliant metadata created with the ESRI ArcGIS 9.2 metadata editor following the FGDC-STD-001-1998 format. This metadata indicated which base data set and DEM were used to orthorectify each photo and corresponding acetate overlay.
3. Orthorectified acetate overlays delivered as 1 bit pixel depth, black and white TIFF format files.
4. Text reports for each photo orthorectification summarizing the average horizontal Root Mean Square inherent in the rectification process.
5. Fully assembled and topologically verified ArcGIS 9.2 personal geodatabase containing polygonal NPS landcover features for the entire project study area. This geodatabase included OGC compliant metadata created with the ESRI ArcGIS 9.2 metadata editor following the FGDC-STD-001-1998 format.

Results and Discussion:

In short, the objectives of this project were successfully met. The use of the higher quality IKONOS DEM and the incorporation of the camera calibration reports in the rectification process generally led to horizontal RMS errors of between 5 and 10 meters. In addition, the selection of between 15 and 20 control points per photo and the care taken by editors when selecting these points definitely contributed to improved georeferencing. The digital product meets the 1:63,360 National Map Accuracy Standard of +/- 32 meters horizontal accuracy for areas where the IKONOS DEM and IKONOS imagery were available.

In areas of the Park where the USGS DOQQ's or DRG's were used for georeferencing and any where the merged DEM was used for orthorectification, there was still horizontal error in the final polygon data. The application of the camera calibration report during orthorectification and careful selection of ground control points for georeferencing allowed for a good product, however, horizontal accuracy in many of these areas still ranged between 10 and 30 meters. Unfortunately, it was not possible to achieve better results in areas where the IKONOS DEM was unavailable.

In areas where the black and white 1993 coastal imagery was used for georeferencing, the horizontal error was considerably higher. Unfortunately, the spatial accuracy of the process that was used to georeference the coastal imagery in the first place was significantly lower than either the IKONOS imagery or the

USGS DOQQ's. As a result, these inaccuracies were transferred to and, in some cases, magnified in this project. The coastal imagery did not line up accurately with any surrounding spatial data layers and in many cases did not even line up with from image to image. The most significant errors were found in the southern most part of the park, particularly in and around Nuka Island. This small island, located in USGS quad Seldovia B2, was comprised of orthorectified photos 4-5, 4-3, 3-39, 3-41. The only data available for georeferencing these photos was the 1993 black and white coastal images. As a result, there is considerable shifting in the landcover polygons in this area.

Another technique that could have been employed to improve the match between the land cover polygons and the orthophoto base map was spatial adjustment. This approach, also called rubber sheeting, involves isolating small areas of spatial data that are displaced from a known correct base layer and then selecting and moving them until they line up with the base. While this approach results in a superior visual product, it is very difficult to quantify because the amount that a given spatial data element is moved to improve its alignment is completely subjective. As a result, it is almost impossible to replicate this type of processing. This approach was not used on the Kenai Fjords project.