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A Feasibility Study to Evaluate Aerial Photogrammetry as a Tool for Assessing Changes in Kenai River Riparian Habitat

by

Mary A. King

December 2007

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

During 2001 and 2002, a feasibility study was conducted to evaluate the ability to apply aerial photogrammetric technologies to older photography to measure changes in riparian habitat as changes in bank position and cover. In 1998 we collected new color, GPS-controlled aerial photographs of the Kenai River. Using technologies proposed by AeroMap U.S., the 1998 controls were applied to selected photographs from 1975 and 1985, with selected photographs being orthorectified to the same scale and modified to a digital format having an accuracy of ±0.5 feet per pixel. We assessed two river sections in each of the three years. This allowed us to compare changes between periods (1975 vs. 1985, 1985 vs. 1998, and 1975 vs. 1998) and to compare expected trends for change with the photogrammetrically measured changes.

Selection of the historic photography is the most critical part of success for this technology. Historic photographs need to be shot at a similar altitude as the current set with the GPS controls. Dates for the photography should be late spring or early summer. All photography should be color. We found that photography in a black and white format or with the presence of snow or ice, particularly shelf ice, was very problematic.

The proposed technology yielded very acceptable results for identification of trends in bank position and landcover change between periods and river reach assessed. We compared the photogrammetric trends with expected trends based upon historic knowledge of each river reach (recreational use, urban development, and geologic history). We also compared specific site bank changes with those obtained in an onground shore angler impact study (King and Hansen *In prep b*) and found that rates of change were similar. Trends in cover change were also generally as expected. We found we had an overall photogrammetric accuracy of ±5 percent error for cover assessment.

This technology appears to be very acceptable for measuring riparian habitat changes and promises to be a useful tool for resource management, particularly for long term monitoring of habitat change and assisting in the development of watershed management plans.

Key words: Aerial photogrammetry, aerial photographs, riparian habitat, habitat assessment, human impact assessment, bank erosion, landcover assessment, GIS, GPS, Kenai River.

INTRODUCTION

BACKGROUND

The Kenai River is located in Southcentral Alaska on the Kenai Peninsula (Figure 1). It is a glacially turbid river with headwaters in Kenai Lake and flows 82 miles westward to its terminus in Cook Inlet. There are three population centers along the Kenai River. The cities of Kenai and Soldotna are located along the lower river and have populations of approximately 6,900 and 3,700, respectively (2000 census). The smaller community of Cooper Landing (population ~370; 2000 census) is located along the upper river, near the outlet at Kenai Lake. These communities and the surrounding area have experienced much growth during the last half-century. This is, in part, due to the development of natural resources in the area. Over the years there has been some mining and logging, but much of the development has been focused around oil and natural gas extraction. A commercial fishery targeting Pacific salmon returning to Cook Inlet has also supported the local economy. During the late 1970s the streams of the Kenai Peninsula became popular sport fishing destinations. This not only provided a seasonal boost in the economy but attracted year round residents.

The Kenai River mainstem supports the largest freshwater sport fishery in Alaska with estimated angler effort exceeding 298,000 days in 2001 (Jennings et al. 2004). Fishing effort occurs throughout the mainstem of the river but it primarily occurs during a relatively short period (June, July, and August) downstream from Skilak Lake. Targeted species include Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, sockeye salmon *O. nerka*, pink salmon *O.*

salmon *O. gorbuscha,* resident rainbow trout *O. mykiss* and Dolly Varden *Salvelinus malma*.

Much of the sport fishing effort on the mainstem Kenai River is directed at early- and late-run Chinook salmon and late-run sockeye salmon. Increased interest occurred in the sport fishery during the mid 1970s when anglers discovered methods for catching Chinook salmon while drifting from powered boats. Further increase in participation occurred in the mid 1980s as shore anglers discovered that sockeye salmon could be caught from the turbid waters of the Kenai River by applying fishing techniques used in the clear waters of the Russian River. These two discoveries contributed to the ever-increasing popularity of the Kenai River as a sport fishing destination. Angler days of effort increased from 122,138 in 1977 (Mills 1980) to 289,165 in 1987 (Mills 1988). Participation in Kenai River fisheries peaked in 1995 with 377,710 angler days of effort (Howe et al. 1996).

The increasing popularity of Kenai River sport fisheries as well as increased urban development along the river corridor have raised concern about human impact to riparian habitat and how this may effect fishery resources. As such, over the years, agencies involved in management of the lands surrounding the Kenai River (to include the United States Forest Service, United States Fish and Wildlife Service and the Alaska Department of Natural Resources-Parks (ADNR); as well as native associations) have enacted regulations to address the concerns. In 1984, through action of the legislature, the Kenai River Special Management Area (KRSMA) was created which placed the Kenai River and adjacent state owned lands under the jurisdiction and management of DNR-Parks with the Alaska Department of Fish and Game (ADF&G) retaining regulatory authority for fishery and wildlife resources. As such the Kenai River Comprehensive Management Plan was written to address increasing pressures on the Kenai River's "ecological system by statewide growth, increased use of the river for both boat and bank fishing, and changes in boat fishing methods and intensity" (ADNR 1998). Prior to 1986, there were no horsepower restrictions for outboard motors used for boating activity on the Kenai River, downstream of Skilak Lake. The maximum allowable horsepower for outboards was reduced to 50 in 1986, and further reduced to 35 in 1987. These horsepower restrictions were done primarily in the interest of safety; but, secondarily, there was a growing concern for increased bank erosion related to boat wakes. These restrictions pertained to power boating activities downstream of Skilak Lake. For the section of the river lying between Kenai and Skilak Lakes, horsepower limitations were implemented in 1986, prohibiting the use of outboards for the majority of this river reach.

In 1996 the Alaska Board of Fisheries (BOF), realizing the importance of maintaining riparian habitats, expressed concern that their regulatory actions not result in further damage to critical riparian habitats along the Kenai River. The BOF stated that they would reconsider the increased inriver allocation of sockeye salmon if additional damage to riparian habitats occurred due to increased shore-based angling. To help mitigate potential impacts to riparian habitats from shore-based angling, the BOF granted the commissioner of ADF&G regulatory authority to close state, federal or municipal riparian habitats to angling if that activity was likely to result in damage to riparian habitat that could negatively affect the fishery resources of upper Cook Inlet. The BOF also asked that the department monitor shore angler use and impacts to Kenai River riparian habitat. Along with the need to address allocative issues, the BOF's continuing concern for reducing riparian habitat impacts was addressed by two regulatory changes in 1999. Both changes were related to impacts to riparian habitat through increased bank erosion due to boat wakes. These same regulatory changes were also promulgated to address allocations between guided and guided and unguided anglers. First, the BOF provided for an unguided, drift only, fishery to occur on Mondays in July, a day previously closed to fishing from boats. This regulation was extended to Mondays in May and June by the BOF in 2002. Second, the BOF implemented a regulation reducing the number of passengers in guided boats during July from six to five (guide plus four clients), effective in 2000. This addressed concerns about increased harvest of Chinook salmon by guided anglers and also addressed concerns for habitat damage caused by boat wakes.

Research projects by other agencies have also investigated habitat impacts due to boating activity, shore angler activity, and urban development along the Kenai River (Scott 1982; Barrick 1984; Reckendorf 1989; Litchfield and Kyle 1991 and 1992; Dorava and Moore 1997; Maynord 2001).

During the winter of 1995-1996, meetings were held on the Kenai Peninsula to discuss the growing concern of urban development along the river and that this could negatively impact fishery resources. In 1996 the Kenai Peninsula Borough passed legislation that implemented a buffer zone, prohibiting most construction within 50 feet of the river.

The Alaska Department of Fish and Game, Division of Sport Fish, has been involved with Kenai River habitat assessment since 1996, including a shore angler impact study (1997-2001; King and Hansen 1999, 2001, 2002; King and Hansen *In prep a, b*). With the growing awareness and concern for human impacts to Kenai River habitat, ADF&G, in 1997, began to explore methods for broad scale assessment and monitoring of habitat change along the riparian corridor of the Kenai River. To this end, we contracted with AeroMap U.S. in 1998 to begin a feasibility study to evaluate proposed technology using aerial photography to assess habitat change. The proposed technology required acquisition of new color, controlled (using geographic positioning systems-GPS) aerial photographs of the Kenai River and overlaying those controls on selected historic photo sets. Specifically, this would allow all photo sets to be ortho-rectified to the same scale to provide the capability of comparing area and distance changes for selected criteria between years. The new photography was obtained in June 1998; evaluation, mapping and analyses were conducted during 2001 and 2002. This report summarizes results of the feasibility study and makes recommendations for appropriate future use of the technology as a resource management tool.

DESIGN

This project was designed to assess bank position and cover class changes for specific time periods. We selected historic photo sets that would allow comparison of change for a time period of lesser development and recreational use on the river with a time period of greater development and recreational use. We also selected historic photo sets using criteria similar to that of the photography obtained on June 14 and 15, 1998. An early to mid June date for this flight was selected to assure complete snow melt from the shoreline while minimizing levels of deciduous foliage. This would provide us the greatest visibility to assess the location of the bank line. Color photography was the desired format for identification of vegetation cover classes while also distinguishing structures, bare ground and a bank line. The 1998 flight was conducted at an altitude of 1,000 feet (map scale of 1:12,000 or 1 inch = 1,000 feet) to support photogrammetric orthophoto production at a scale of 1:2,400 (1 inch = 200 feet). For later assessment, this translated to a digital resolution of 1 pixel equal to 0.5 foot. Therefore, selection of historic photo sets needed to comply with these criteria:

1. Photo set extent: Skilak Lake to Cook Inlet.
2. Years:
    a. Photo set #1: mid 1970s or earlier.
    b. Photo set #2: early to mid 1980s.
3. Period of flight: late May to late June.
4. Map scale: 1 inch = 500 feet to 1,500 feet.
5. Photography format: color, but black and white was acceptable.

After selecting 1975 (flight dates: June 26 and July 6, scale: 1 inch = 1,320 feet) and 1985 (flight date: May 28, scale: 1 inch = 1,000 feet) photo sets, we selected subsections of the river for the feasibility study. Area A (river miles 15 through 21) and Area B (river miles 24.5 through 26.5) were selected using these criteria:

1. Area A: the geologic characteristics of this reach showed it to be meandering with less bank and channel armor; hence, more susceptible to erosion. In the mid 1970s urban development and recreational use were already occurring.
2. Area B: this reach was deeply entrenched and highly armored; its geologic history defining it to be less susceptible to erosion. In the mid 1970s there was essentially no development or recreational use in this river section.
3. Both river sections were located in areas that were assessed during ADF&G's shore angler impact study (King and Hansen 1999). This would allow some comparison and ground-truthing of changes.

OBJECTIVES

Specific objectives of this feasibility study were to evaluate the application of the proposed technology in:

1. Estimating Kenai River bank position changes to the nearest 12 inches, using aerial photogrammetry technology applied to Area A and Area B, for three time periods: 1975 vs. 1985 (period 1), 1985 vs. 1998 (period 2), 1975 vs. 1998 (period 3).
2. Estimating changes in cover by cover class (area and percent cover) within a 200 foot corridor along each bank of the Kenai River, using aerial photogrammetry technology applied to Area A and Area B, for three periods: 1975 vs. 1985, 1985 vs. 1998, 1975 vs. 1998.

Tasks included:

1. Developing a set of orthorectified digital photos for Area A and Area B for each year assessed (1975, 1985, and 1998).
2. Summarizing cover changes through time (1975 to 1985 to 1998) for Area A and Area B by total area and percent cover for each cover class sequence (ex. Tree cover in 1975-cleared area cover in 1985-structure cover in 1998).
3. Estimating measurement error by comparison of areas measured by two methods: photogrammetric and onground.

METHODS

DIGITAL ORTHO PHOTOGRAPHY

Selected photos for each study area and year were scanned (0.5 foot pixel resolution) and orthorectified and stored in a digital format. Initially, selected photos from the newly collected 1998 GPS controlled photography underwent a series of transformations:

1. Aerotriangulation: this process combined the GPS airborne camera station controls with designated ground controls to provide accurate controls for mapping.
2. Creation of digital terrain models (DTMs): specifically designed software (proprietary) was used to collect elevation data to provide general characteristics of terrain. These data were collected at 1 inch equivalents for final map scale. The data were used to create a "wire frame" for image correlation and ortho-rectification resulting in a horizontal map scale of 1 inch = 200 feet.
3. Digital orthophotos: designated photos were scanned at 200 dpi (dots per inch) to deliver half-foot pixel resolution, necessary for accurate assessment of bank and cover changes. After the DTM was created and the raster images were rectified to true map scale, the images were mosaiced, producing seamless orthophotos.

Once the 1998 baseline digital orthophotos were prepared, the map controls were transferred to the photography lacking controls (the selected photos from the 1975 and 1985 photo sets). This was done using a "control transfer device" (proprietary). The scanned photos (1975 and 1985) were "draped" over the DTM wire frame to generate digital orthophotos, corrected to identical scale. This allowed comparison for change detection.

PLANIMETRIC MAPS

AeroMap used DAT/EM software and analytical stereoplotter instruments to generate digital planimetric map files. Files included planimetric features such as the bank position line as well as the various landcover classes to be assessed. Features were compiled for import into ArcMap/ArcView. The resultant file was formatted as a single map sheet for import and output in AutoCad and ArcView formats to CD-ROM media.

Bank Position Change

To measure bank position changes we defined the bank edge as the top of the riverbank rather than at waterline. This was necessary due to the variability in seasonal discharge that would alter the bank line location if it was based on the waterline. In most cases the bank edge was determined by the line where the vegetation met the bare ground associated with the beginning of the bank slope. In some instances this delineation was not clear due to absence of vegetation. In these cases, the change in slope was used to further define the bank edge. Familiarity with the Kenai River lends much insight to appropriately locating the bank edge. Initially, AeroMap staff located the bank edge in some locations based upon land contours. Because the Kenai River valley was glacially formed, there are river terraces present. There was confusion in location of the bank edge when a river terrace existed and AeroMap staff incorrectly positioned the bank edge at a more onshore location. Early review of the mapping process trained AeroMap staff to correctly locate the bank edge in these situations and minimize error. Another potential source for error was overhanging vegetation which might conceal the bank edge resulting in an estimate for the actual location. The Kenai River is a large glacial river, not having a closed canopy. By using paired photographs and steroscopes, experienced technicians were able to delineate the bank edge with acceptable error limited by the resolution of the photography.

Once AeroMap staff identified the bank edge as a line, these data were imported into AutoCad software. For each study area the bank position lines for each year were plotted. The intersection of the lines between years created polygons for which area could be calculated. Each polygon represented gain (possible accretion) or loss (possible erosion) in bank position for the time periods being compared. For analyses, the AutoCad files were translated into ArcInfo. This allowed error checking and calculation of the thematic data classes (total erosion and accretions). Summation of areas for all gain in bank position change polygons provided an estimate of total gain in bank position change for the time period being assessed. A similar process was done to acquire an estimate for total loss in bank position change. This was done for mainland banks as well as islands. Paired assessments were done for all three time periods.

Finalized bank position lines were plotted on planimetric maps along with tables summarizing total changes in bank position by period. Using these data, we formed imaginary polygons along each riverbank for each study area. These polygons were equal-width bands and the width represented the uniform measured bank position change for the entire riverbank within each study area. Formation of these polygons allowed us to estimate the overall average annual bank position change by period and study area:

$$W_i = \frac{\dfrac{N_i * (6{,}272{,}640\,in^2/acre)}{b} \Big/ M_i * (63{,}360\,in/mi)}{T} \qquad (1)$$

where:

- W_i = width, in inches, of an imaginary, uniform width polygon on each riverbank in study area *i*.
- N_i = acres of bank position change in study area *i*.
- b = number of banks (2).
- M_i = river miles in study area *i* (Area A = 6, Area B = 2).
- T = years in the period (10, 13, or 23).

This is referred to as the uniform bank position gain, loss, or change.

Landcover Change

To assess changes in landcover in the riparian zone we assessed a corridor that extended 200 feet shoreward from each bank edge. AeroMap staff first identified the bank edge and then specified the 200-foot corridor. To classify cover types AeroMap staff used standard photogrammetric techniques employing analytical stereoscopes. All landcover within the 200-foot corridor was identified. The landcover classes were defined as:

1. Trees: tall shrubs and trees.
2. Groundcover: grasslands, herbaceous plants, and small shrubs (brush). Lawns were included here as there was no way to distinguish between a lawn and grassland, other than proximity to a structure, which was deemed too subjective.
3. Cleared area: roads, parking areas, gravel surfaces.
4. Structure: buildings, trailer homes (more permanently located), docks, boardwalks, and other man-made structures.
5. Pond: any standing, enclosed bodies of water.
6. Backwater/Creeks: seasonally watered areas in proximity to the river, and tributaries.
7. Harbor: man-made excavations along the river for the purpose of boat moorage. For general interest, we also classified harbor outside the 200-foot corridor, which allowed an estimate for total area of harbor.
8. River: flowing waters of the Kenai River.
9. Substrate: any exposed gravel within the river channel (i.e., between the delineated bank position lines). This included gravel bars in the channel, seasonally exposed river substrate, and gravel faced banks or island perimeters.
10. Vegetated bank face: any mainland vegetation occurring between the bank line and the waterline.

Landcover data were imported into AutoCad and ArcView software. The project biologist assisted AeroMap staff with review of these data to error check, thus improving accuracy of classifications. Classifications were reviewed using the orthophotography as well as the project biologist's knowledge of the study area. For analyses, the AutoCad files were translated into ArcInfo. This allowed further error checking and calculation of the thematic data classes for landcover.

Final landcover class data were plotted on planimetric maps along with tables summarizing total acres of landcover by class by year and changes in landcover by class between years. We also estimated the annual average rate of change for each landcover class by period and study area.

LANDCOVER CLASS TRANSITION

Realizing that changes in landcover occur naturally as well as from human activity, it was important to summarize transitions that were occurring between landcover classes over time. For example, if an area was classified as trees in 1975, it was also important to track how that same area was classed in 1985, and again in 1998. In some cases an area may have been classed as trees in 1975, partially trees and shrubs in 1985, and by 1998 some of the shrub class may have matured back to trees. In other words, an area that had been impacted by human activity had partially recovered. It was informative to identify these types of transitions, as well as naturally occurring succession.

Using ArcView software, the 1975 landcover class assignments were tracked through 1985 and 1998. We identified all permutations of each 1975 landcover class (e.g., tree class in 1975, shrub class in 1985, cleared area class in 1998). The total area for each permutation was estimated. Because of the large number of categories created by all permutations, it was necessary to consolidate these data into more meaningful categories: no impact; impact, recovering; and impact. "No impact" categories were characterized as those having no change or undergoing natural succession. "Impact, recovering" categories were characterized as those receiving some type of impact in 1975 or 1985, but showing either revegetation or maturing vegetation by 1998. "Impact" categories were characterized as areas receiving impact in at least one of the three years and not recovering during any of the three time periods, as well as possibility of permanent bank position loss. Within each of these categories were subcategories (See footnotes for Tables 4 and 5 for definitions.):

1. No impact:
    a. Successional.
    b. Natural, no change.
    c. Shoreline transition.
    d. Vegetated bank face, unchanged.
    e. Substrate, unchanged.
    f. River, unchanged.
2. Impact, Recovering:
    a. Natural - impact (clearing) - recovering
    b. Natural – impact – recovering.
    c. Impact – recovering.
3. Impact:
    a. Natural – impact – river.
    b. Natural – natural – impact.
    c. Natural – impact – impact.
    d. Natural – natural – impact (clearing).
    e. Natural – impact (clearing) – impact.
    f. Natural – impact (clearing) – river/substrate.
    g. Impact, no change.
    h. Impact – river/substrate.
    i. Impact – recovering – impact.
    j. Impact – recovering- river/substrate.

Each of these permutations was summarized by location (mainland, island, or channel) for each study area.

MEASUREMENT ERROR

To error check photogrammetric estimates of area, we conducted on-ground measurements of easily identifiable polygons. The ground-truthing was done in 2002, three years after the photography was acquired; therefore, we ground-truthed "structures" because these were rigid and least likely to have changed shape since 1998. Before measuring a structure we inquired with the landowner as to any changes in the structure since 1998. Realizing that photogrammetric area was estimated based upon roof dimensions, rather than the ground footprint, we attempted to measure sides of structures based upon the corners of the eaves. Since we wished to minimize our intrusion, we tried to drop a vertical line from the corner of an eave to the ground and then measure the distance between the vertically adjusted stadia rods located at these points. It was not feasible to measure the actual sides of the structure and later account for the dimensions of the eaves because within a single structure we found considerable variation in the width of eaves. After calculating these areas, we determined the percent error between on-ground and photogrammetric estimates.

Due to the lag in time for conducting measurement error, we did not ground truth area estimates for other landcover classes. Instead, we relied upon the long term experience of the staff at AeroMap whose expertise in classification had been evaluated as ±5% of the true value.

RESULTS

DIGITAL ORTHO PHOTOGRAPHY

Digital ortho photographs were produced for each study area for each year (1975, 1985, and 1998) assessed. Printed copies of these appear in Appendix A.

BANK POSITION CHANGE

For mainland banks in Area A during period 1, there was an overall loss of -2.8 acres of riverbank, or an average of -0.3 acres/year (Table 1). This equates to a uniform average loss along each riverbank (average annual change in width of bank change polygon) of -2.3 inches/year. In period 2, there was a loss of -7.7 acres of riverbank (average of -0.6 acres/year) with a uniform average loss along the riverbank of -4.9 inches/year. In period 3, there was a loss of -10.5 acres of riverbank (average of -0.5 acres/year) with a uniform average loss of -3.8 inches/year.

For mainland banks in Area B in period 1, there was an overall loss of -2.2 acres of riverbank, or an average of -0.2 acre/year with a uniform average loss along each riverbank of -5.5 inches/year (Table 1). In period 2, there was an overall loss of -0.1 acres of riverbank (average of <0.1 acre/year) with a uniform average loss along the riverbank of -0.2 inches/year. In period 3, there was an overall loss of -2.4 acres of riverbank (average of -0.1 acres/year) with a uniform average loss of -2.5 inches/year.

Table 1.–Analyses of bank position change for Area A (rivermiles 15 -21) and Area B (rivermiles 24.5 - 26.5), Kenai River, 1975 - 1985, 1985 - 1998, 1975 - 1998.

	Period 1 (1975 - 1985)				Period 2 (1985 - 1998)				Period 3 (1975 - 1998)			
		Annual	Wdth of Bk Chnge Polygon[b]			Annual	Wdth of Bk Chnge Polygon			Annual	Wdth of Bk Chnge Polygon	
	Acres	Change (acre)[a]	Total (in)[c]	Annual (in/yr)[d]	Acres	Change (acre)	Total (in)	Annual (in/yr)	Acres	Change (acre)	Total (in)	Annual (in/yr)
Area A												
Mainland Banks												
Gain	4.4	0.4	36.1	3.6	2.9	0.2	24.0	1.8	1.5	0.1	12.7	0.6
Loss	-7.2	-0.7	-59.1	-5.9	-10.6	-0.8	-87.7	-6.7	-12.1	-0.5	-99.5	-4.3
Change	-2.8	-0.3	-23.0	-2.3	-7.7	-0.6	-63.8	-4.9	-10.5	-0.5	-86.8	-3.8
Islands[e]												
Gain	0.4	0.0			2.0	0.2			1.0	0.0		
Loss	-2.2	-0.2			-0.6	0.0			-1.4	-0.1		
Change	-1.8	-0.2			1.4	0.1			-0.4	0.0		
Area B												
Mainland Banks												
Gain	0.9	0.1	21.2	2.1	1.5	0.1	36.8	2.8	0.2	0.0	3.8	0.2
Loss	-3.1	-0.3	-76.7	-7.7	-1.6	-0.1	-39.8	-3.1	-2.5	-0.1	-62.4	-2.7
Change	-2.2	-0.2	-55.5	-5.5	-0.1	0.0	-3.1	-0.2	-2.4	-0.1	-58.6	-2.5
Islands												
Gain	0.3	0.0			0.0	0.0			0.0	0.0		
Loss	0.0	0.0			-0.5	0.0			-0.3	0.0		
Change	0.3	0.0			-0.5	0.0			-0.2	0.0		

[a] Annual change = average total acres of change per year for the period assessed.

[b] This is the width an imaginary polygon (a narrow band of uniform width) placed along each bank and represents the average amount of bank loss/gain for the assessed area per bank.

[c] This is the total width of the bank change polygon for all years assessed.

[d] This is the average width of the bank change polygon for all years assessed and would represent the annual average rate of change in inches per year.

[e] Islands were not analyzed for the width of the bank polygon because we did not estimate perimeters and there was little change.

Island changes for Area A showed an overall loss of -1.8 acres (average of -0.2 acres/year) in period 1, a gain of 1.4 acres (average of 0.1 acres/year) in period 2, and a loss of -0.4 acres (negligible annual average change) in period 3 (Table 1). For Area B islands, there was an overall gain of 0.3 acres in period 1, a loss of -0.5 acres in period 2, and a loss of -0.2 acres in period 3. There was negligible annual average change for all periods. Estimates of the width of the bank change polygon for islands were not done because we did not estimate the perimeters of islands.

LANDCOVER CHANGE

AeroMap staff tried several automated approaches for landcover classification. The intent of an automated approach was to reduce subjectivity as well as increase accuracy and efficiency. An explanation of these approaches and why they were not used is discussed in a separate report appearing in Appendix B. AeroMap staff resolved that photogrammetrically derived data yielded better accuracy in regards to location and class.

Figures 6 and 7 are examples of the planimetric landcover map for each area. Figure 6 shows Poacher's Cove in Area A. In 1975, there are some structures and roads present along with the initial excavation of the boat harbor. In 1985, more structures are present and the road system is more developed. By 1998, there are considerably more structures, but minimal change in the road system. Notice the presence of an island near the left bank in 1975 that through possible sedimentation appears to have been incorporated into the mainland by 1985. On the larger island, note the successional transition of the tree class from 1975 to 1998. Also, note the channel substrate present in 1985 due to low discharge. Figure 7 shows Moose Range Meadows in Area B that in 1975 had no development aside from a small cleared area. In 1985, one structure was present, and the cleared area from 1975 had revegetated to groundcover. By 1998, much more development was present in the form of structures, cleared area, and loss of trees to groundcover. Also, note in 1985 the continuous band of channel substrate present along both riverbanks. These figures simply provide a visual assessment of the cover class assignments and how change was assessed over time.

Tables 2 (Area A) and 3 (Area B) show estimates of total area in acres and percent cover for each landcover class by location (mainland, island, and combined) and year. These tables also show changes in total cover and percent cover for each landcover class location and period. The focus of results will be on combined (mainland plus island) primary landcover classes (trees, groundcover, cleared area, structures, harbor), excluding landcover classes for natural bodies of water (pond, backwater/creek) and those occurring between the river banks (river, substrate, vegetated bank face).

In Area A we assessed 350.6 acres of upland (Table 2). The cover for trees decreased from 1975 (227.2 acres, 32.5%) to 1985 (194.3 acres, 27.8%), and then increased slightly in 1998 (205.7 acres, 29.4%) (Table 2, Figure 8). Groundcover increased slightly from 1975 (104.1 acres, 14.9%) to 1985 (118.5 acres, 16.9%) and then had a large decrease by 1998 (89.4 acres, 12.8%). Cover for cleared areas increased over time: 1975 (14.3 acres, 2%), 1985 (24.6 acres, 3.5%), 1998 (29.2 acres, 4.2%). For Area A we also assessed cover for harbors. Within the 200 ft study area limits, there was a doubling of cover for harbors over time: 1975 (1.8 acres, 0.3%), 1985 (3.1 acres, 0.4%), 1998 (3.6 acres, 0.5%). For general interest, we also estimated total cover of

Table 2.–Summary of Area A (rivermiles 15-21) landcover class analyses, Kenai River.

	Landover						Landcover Change								
	1975		1985		1998		Period 1 (1975 to 1985)			Period 2 (1985 to 1998)			Period 3 (1975 to 1998)		
	Acres	%	Acres	%	Acres	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%
Mainland															
Trees	213.1	30.5	185.6	26.5	192.9	27.6	-27.6	-2.8	-3.9	7.3	0.6	1.0	-20.2	-0.9	-2.9
Groundcover (grassland, herb, shrub)	90.3	12.9	105.4	15.1	79.7	11.4	15.2	1.5	2.2	-25.8	-2.0	-3.7	-10.6	-0.5	-1.5
Cleared area (roads, gravel, parking)	14.3	2.0	23.4	3.3	28.0	4.0	9.1	0.9	1.3	4.6	0.4	0.7	13.7	0.6	2.0
Structure (decks, docks, bldgs.)	1.8	0.3	4.6	0.7	10.7	1.5	2.8	0.3	0.4	6.1	0.5	0.9	8.9	0.4	1.3
Pond	0.4	0.1	0.5	0.1	0.4	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0
Backwater/Creek	1.0	0.1	0.3	0.0	1.7	0.2	-0.7	-0.1	-0.1	1.4	0.1	0.2	0.7	0.0	0.1
Harbor	1.8	0.3	3.1	0.4	3.6	0.5	1.2	0.1	0.2	0.5	0.0	0.1	1.7	0.1	0.2
River	337.1	48.2	257.1	36.8	348.3	49.8	-80.0	-8.0	-11.4	91.2	7.0	13.0	11.2	0.5	1.6
Substrate	2.7	0.4	72.9	10.4	2.5	0.4	70.2	7.0	10.0	-70.4	-5.4	-10.1	-0.2	0.0	0.0
Vegetated Bank Face	8.5	1.2	7.9	1.1	6.9	1.0	-0.6	-0.1	-0.1	-1.0	-0.1	-0.1	-1.6	-0.1	-0.2
Total upland[a]	322.7	46.1	322.8	46.1	316.8	45.3	0.1	0.0	0.0	-6.0	-0.5	-0.9	-5.9	-0.3	-0.8
Total area	671.0		*660.7*		*674.5*		*-10.3*			*13.8*			3.5		
Island															
Trees	14.0	2.0	8.7	1.2	12.8	1.8	-5.3	-0.5	-0.8	4.0	0.3	0.6	-1.3	-0.1	-0.2
Groundcover (grassland, herb, shrub)	13.8	2.0	12.9	1.8	9.7	1.4	-0.9	-0.1	-0.1	-3.2	-0.2	-0.5	-4.2	-0.2	-0.6
Cleared area (roads, gravel, parking)	0.0	0.0	1.3	0.2	1.3	0.2	1.3	0.1	0.2	0.0	0.0	0.0	1.3	0.1	0.2
Structure (decks, docks, bldgs.)	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.0	0.0	0.5	0.0	0.1	0.6	0.0	0.1
Substrate	0.8	0.1	16.0	2.3	0.9	0.1	15.2	1.5	2.2	-15.1	-1.2	-2.2	0.1	0.0	0.0
Total upland	27.9	4.0	22.9	3.3	24.3	3.5	-4.9	-0.5	-0.7	1.3	0.1	0.2	-3.6	-0.2	-0.5
Total area	28.7		*38.9*		25.2		*10.3*			*-13.8*			-3.5		
Combined															
Trees	227.2	32.5	194.3	27.8	205.7	29.4	-32.9	-3.3	-4.7	11.4	0.9	1.6	-21.5	-0.9	-3.1
Groundcover (grassland, herb, shrub)	104.1	14.9	118.4	16.9	89.4	12.8	14.3	1.4	2.0	-29.0	-2.2	-4.1	-14.7	-0.6	-2.1
Cleared area (roads, gravel, parking)	14.3	2.0	24.6	3.5	29.2	4.2	10.4	1.0	1.5	4.6	0.4	0.7	15.0	0.7	2.1
Structure (decks, docks, bldgs.)	1.8	0.3	4.6	0.7	11.2	1.6	2.8	0.3	0.4	6.6	0.5	0.9	9.4	0.4	1.3
Pond	0.4	0.1	0.5	0.1	0.4	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0
Backwater/Creeks	1.0	0.1	0.3	0.0	1.7	0.2	-0.7	-0.1	-0.1	1.4	0.1	0.2	0.7	0.0	0.1
Harbor	1.8	0.3	3.1	0.4	3.6	0.5	1.2	0.1	0.2	0.5	0.0	0.1	1.7	0.1	0.2
River	337.1	48.2	257.1	36.8	348.3	49.8	-80.0	-8.0	-11.4	91.2	7.0	13.0	11.2	0.5	1.6
Substrate	3.5	0.5	88.9	12.7	3.3	0.5	85.4	8.5	12.2	-85.6	-6.6	-12.2	-0.1	0.0	0.0
Vegetated Bank Face	8.5	1.2	7.9	1.1	6.9	1.0	-0.6	-0.1	-0.1	-1.0	-0.1	-0.1	-1.6	-0.1	-0.2

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Table 2.–Page 2 of 2.

	Landover						Landcover Change								
	1975		1985		1998		Period 1 (1975 to 1985)			Period 2 (1985 to 1998)			Period 3 (1975 to 1998)		
	Acres	%	Acres	%	Acres	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%
Summary of Upland Area Only (uses 1975 total area as base for percent cover)															
Total upland	350.6	100.0	345.7	98.6	341.1	97.3	-4.9	-0.5	-1.4	-4.6	-0.4	-1.3	-9.5	-0.4	-2.7
Total vegetation	331.3	94.5	312.7	89.2	295.0	84.1	-18.6	-1.9	-5.3	-17.6	-1.4	-5.0	-36.2	-1.6	-10.3
Total development	17.9	5.1	32.3	9.2	44.0	12.5	14.4	1.4	4.1	11.7	0.9	3.3	26.1	1.1	7.4
Total natural water bodies	1.4	0.4	0.8	0.2	2.1	0.6	-0.6	-0.1	-0.2	1.3	0.1	0.4	0.7	0.0	0.2
Base area difference (bank change)[b]	0.0	0.0	-4.9	-1.4	-9.5	-2.7	-4.9	-0.5	-1.4	-4.6	-0.4	-1.3	-9.6	-0.4	-2.7
Base Area (1975)	350.6		350.6		350.6										
Harbor Summary[c]															
Inside study area 200' limit	1.8	0.3	3.1	0.4	3.6	0.5	1.2	0.1	0.2	0.5	0.0	0.1	1.7	0.1	0.2
Outside study area 200' limit	0.1		5.3		5.0		5.3	0.5		-0.3	0.0		5.0	0.2	
Total	1.9		8.4		8.6		6.5	0.7		0.2	0.0		6.7	0.3	

[a] Upland is defined as the sum of all landcover classes exclusive of the river channel (substrate, river, and vegetated bank face).

[b] This accounts for the change in size of the upland area, either due to bank loss or error in locating the bankline.

[c] Harbor areas were assessed for inside the 200 foot study area as well as outside.

harbors, to include outside the 200 ft study area limits: 1975 (1.9 acres), 1985 (8.4 acres), 1998 (8.6 acres).

In Area B we assessed 106.2 acres of upland (Table 3). The cover for trees decreased over time: 1975 (70.5 acres, 32.0%), 1985 (63.5 acres, 28.8%), 1998 (55.6 acres, 25.2%) (Table 3, Figure 8). Groundcover increased over time: 1975 (35.1 acres, 15.9%), 1985 (37.9 acres, 17.2%), 1998 (39.3 acres, 17.8%). Cover for cleared areas increased over time: 1975 (0.7 acres, 0.3%), 1985 (2.4 acres, 1.1%), 1998 (6.8 acres, 3.1%). Cover for structures increased over time: 1975 (0 acres), 1985 (0.2 acres, 0.1%), 1998 (3.1 acres, 1.4%). There were no harbors in Area B.

LANDCOVER CLASS TRANSITION

Appendix C provides a summary of all permutations of the 1975 landcover class assignments by area (A and B) and location within area (mainland, island, channel). These appendices list the number of assessed polygons for each permutation, related statistics (minimum, maximum, and average area; variance, total area) and the transition code.

Using the transition codes, the permutations were regrouped and summarized by area and location. Area A was comprised of 697.8 acres with 608.2 acres (87.2%) estimated to have received “no impact” from 1975 through 1998 (Table 4). There were 33.6 acres (4.9%) classified as “impacted, recovering” and 55.5 acres (8%) classified as “impacted”. Area B was comprised of 220.5 acres of which 193.8 acres (87.9%) had “no impact”, 16.8 acres (7.6%) were “impacted, recovering”, and 9.9 acres (4.5%) were impacted (Table 5).

MEASUREMENT ERROR

To determine the measurement error, we measured 33 structures. Although a larger number of structures were selected, the actual number measured was related to land owner cooperation and modifications to the structure since 1998. Area estimates (photogrammetric and on-ground) for these structures and percent error between methods are listed in Appendix D. The initial summary data (trial 1) showed a mean percent error of –4.2, having an error range of –14 to 13 (Table 6). Of the photogrammetrically derived structural areas, 23 (70%) structures were underestimated and 10 (30%) were overestimated.

DISCUSSION

BANK POSITION CHANGE

For Area A, the mainland bank position changes were as might be expected. This is a river reach that is geologically more susceptible to loss in bank position due to the effects of erosion. It had some level of urban development and recreational use in 1975; and, these human uses increased greatly during the 1980s and 1990s. It would be expected that these types of uses, in combination with geologic characteristics of the river, would have the cumulative impact of increasing bank erosion through time. The results show a greater than two-fold loss of mainland bank in period 2 (-7.7 acres) than period 1 (-2.8 acres; Table 1 and Figure 2) and, thus a two-fold increase in the annual average rate of change (width of bank change polygon) between period 1 (-2.3 inches/year) and period 2 (-4.9 inches/year).

For Area B the mainland bank position changes did not reflect the expected change in bank position (i.e., greater bank loss in period 2 than period 1). As this is a geologically more stable river reach, natural erosion was expected to be minimal. Urban development, though not present

Table 3.–Summary of Area B (rivermiles 24.5-26.5) landcover class analyses, Kenai River.

	Landcover						Landcover Change								
	1975		1985		1998		Period 1 (1975 to 1985)			Period 2 (1985 to 1998)			Period 3 (1975 to 1998)		
	Acres	%	Acres	%	Acres	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%
Mainland															
Trees	70.3	31.9	63.4	28.7	55.3	25.1	-6.9	-0.7	-3.1	-8.0	-0.6	-3.6	-14.9	-0.6	-6.8
Groundcover (grassland, herb, shrub)	34.0	15.4	36.8	16.7	38.3	17.4	2.8	0.3	1.3	1.5	0.1	0.7	4.3	0.2	2.0
Cleared area (roads, gravel, parking)	0.7	0.3	2.4	1.1	6.8	3.1	1.7	0.2	0.8	4.4	0.3	2.0	6.1	0.3	2.8
Structure (decks, docks, bldgs.)	0.0	0.0	0.2	0.1	3.1	1.4	0.2	0.0	0.1	2.9	0.2	1.3	3.1	0.1	1.4
Pond	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River	114.3	51.8	104.0	47.2	115.7	52.5	-10.3	-1.0	-4.7	11.7	0.9	5.3	1.4	0.1	0.7
Substrate	0.0	0.0	11.0	5.0	0.0	0.0	11.0	1.1	5.0	-11.0	-0.8	-5.0	0.0	0.0	0.0
Vegetated Bank Face	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total upland	104.9	47.6	102.9	46.6	103.5	47.0	-2.1	-0.2	-0.9	0.7	0.1	0.3	-1.4	-0.1	-0.6
Total area	219.2		217.9		219.2		-1.4			1.4			0.0		
Island															
Trees	0.2	0.1	0.2	0.1	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1
Groundcover (grassland, herb, shrub)	1.1	0.5	1.0	0.5	0.9	0.4	-0.1	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	-0.1
Cleared area (roads, gravel, parking)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure (decks, docks, bldgs.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Substrate	0.0	0.0	1.4	0.6	0.0	0.0	1.4	0.1	0.6	-1.4	-0.1	-0.6	0.0	0.0	0.0
Total upland[a]	1.3	0.6	1.2	0.6	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total area	1.3		2.6		1.2		1.4			-1.4			0.0		
Combined															
Trees	70.5	32.0	63.5	28.8	55.6	25.2	-6.9	-0.7	-3.1	-7.9	-0.6	-3.6	-14.8	-0.6	-6.7
Groundcover (grassland, herb, shrub)	35.1	15.9	37.9	17.2	39.3	17.8	2.8	0.3	1.3	1.4	0.1	0.6	4.2	0.2	1.9
Cleared area (roads, gravel, parking)	0.7	0.3	2.4	1.1	6.8	3.1	1.7	0.2	0.8	4.4	0.3	2.0	6.1	0.3	2.8
Structure (decks, docks, bldgs.)	0.0	0.0	0.2	0.1	3.1	1.4	0.2	0.0	0.1	2.9	0.2	1.3	3.1	0.1	1.4
Pond	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River	114.3	51.8	104.0	47.2	115.7	52.5	-10.3	-1.0	-4.7	11.7	0.9	5.3	1.4	0.1	0.7
Substrate	0.0	0.0	12.4	5.6	0.0	0.0	12.4	1.2	5.6	-12.4	-1.0	-5.6	0.0	0.0	0.0
Vegetated Bank Face	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table 3.–Page 2 of 2.

Total upland	1975		1985		1998		Period 1 (1975 to 1985)			Period 2 (1985 to 1998)			Period 3 (1975 to 1998)		
Total vegetation	Acres	%	Acres	%	Acres	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%	Acres	Acres/Yr	%
Total development															
Total natural water bodies	106.2	48.2	104.1	47.2	104.8	47.5	-2.1	-0.2	-1.0	0.7	0.1	0.3	-1.4	-0.1	-0.6
Total channel	105.5	47.9	101.4	46.0	94.9	43.0	-4.1	-0.4	-1.9	-6.5	-0.5	-2.9	-10.6	-0.5	-4.8
Total Study Area	0.7	0.3	2.6	1.2	9.9	4.5	2.0	0.2	0.9	7.2	0.6	3.3	9.2	0.4	4.2
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	114.3	51.8	116.4	52.8	115.7	52.5	2.1	0.2	1.0	-0.7	-0.1	-0.3	1.4	0.1	0.7
Total upland	220.5		220.5		220.5										
Total vegetation															
Total development															
Total natural water bodies	106.2	100.0	104.1	98.0	104.8	98.7	-2.1	-0.2	-2.0	0.7	0.1	0.7	-1.4	-0.1	-1.3
Base area difference (bank change)[b]	105.5	99.4	101.4	95.5	94.9	89.4	-4.1	-0.4	-3.9	-6.5	-0.5	-6.1	-10.6	-0.5	-10.0
Base area 1975	0.7	0.6	2.6	2.5	9.9	9.3	2.0	0.2	1.9	7.2	0.6	6.8	9.2	0.4	8.7
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	-2.1	-2.0	-1.4	-1.3	-2.1	-0.2	-2.0	0.7	0.1	0.7	-1.4	-0.1	-1.3
	106.2														

[a] Upland is defined as the sum of all landcover exclusive of the river channel (substrate, river, and vegetated bank face).

[b] This accounts for the change in size of the upland area, likely due to bank loss.

Table 4.–Summary of transition of grouped landcover classes (1975 to 1985 to 1998) in acres, study area A, Kenai River.

	Mainland							Island					Channe	Total		Percent	
Grouped Landcover Class[a]	Groundcov	Tre	Backwat	Pon	Harb	Cleare	Structu	Groundcov	Tre	Substra	Cleare	Structu		Actu	Adjuste	Actu	Adjuste
No Impact																	
Successional	24.		0.	0.				3.	0.					28.	28.	4.	8.
Natural, no change	43.	158.		0.				4.	6.					213.	213.	30.	61.
Shoreline transition	7.	5.	0.					2.	0.	0.			90.	107.	17.	15.	4.
Vegetated bank face, unchanged													1.	1.		0.	0.
Substrate, unchanged													0.	0.		0.	0.
River, unchanged													256.	256.		36.	0.
Total	75.	164.	1.	0.				10.	7.	0.			348.	608	259.	87	74.
Impact, Recovering																	
Natural-impact (clearing)-recovering		21.							3.					24.	24.	3.	7.
Natural-impact-recovering	1.	1.		0.				0.	0.				0.	4.	4.	0.	1.
Impact, recovering					0.	4.	0.					0.		4.	4.	0.	1.
Total	1.	22.		0.	0.	4.	0.	0.	4.			0.	0.	33	33.	4	9.
Impact																	
Natural-impact-river	0.	0.						0.						0.	0.	0.	0.
Natural-natural-impact	6.	4.		0.				0.	0.				0.	11.	11.	1.	3.
Natural-impact-impact	6.	7.		0.				0.	0.				0.	14.	14.	2.	4.
Natural-natural-impact (clearing)		10.							0.					11.	11.	1.	3.
Natural-impact (clearing)-impact		3.							0.					4.	4.	0.	1.
Natural-impact (clearing)-river/substrate		0.							0.					0.	0.	0.	0.
Impact, no change					1.	8.	1.					0.		11.	11.	1.	3.
Impact-river/substrate					0.	0.	0.							0.	0.	0.	0.
Impact-recovering-impact					0.	1.	0.							1.	1.	0.	0.
Impact-recovering-river/substrate						0.	0.							0.	0.	0.	0.
Total	13.	26.		0.	1.	9.	1.	0.	2.			0.	0.	55	55.	8	15.
														697.	348.		

[a] Definitions of grouped landcover classes:

Impact, no change: originally impacted and remained impacted

Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.

Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.

Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.

Natural-impact-impacted: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)

Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

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Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.

Natural, no change: the 1975 vegetation class was unchanged through the study period.

Natural-impacted (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.

Natural-impacted (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.

Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.

Natural-natural-impacted (cleared): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.

River, unchanged: classified as a river for each year assessed.

Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).

Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.

Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.

Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

[b] Acreage values and percentages were adjusted to exclude classes occurring in the river channel (river, substrate, vegetated bank face, etc.)

Table 5.–Summary of transition of grouped landcover classes (1975 to 1985 to 1998) in acres, study area B, Kenai River.

	Mainland							Island					Channe	Total		Percent	
Grouped Landcover Class[a]	Groundcov	Tre	Backwat	Pon	Harb	Cleare	Structu	Groundcov	Tre	Substra	Cleare	Structu		Actu	Adjuste	Actu	Adjuste
No Impact																	
Successional	6.							0.						6.	6.	2.	6.
Natural, no change	21.	46.						0.	0.					69.	69.	31.	65.
Shoreline transition	3.	0.						0.					10.	14.	3.	6.	3.
Substrate, unchanged													0.	0.		0.	
River, unchanged													103.	103.		47.	
Total	31.	46.						1.	0.				114.	193	79.	87	74.
Impact, Recovering																	
Natural-impact (clearing)-recovering		5.												5.	5.	2.	5.
Natural-impact-recovering	0.	0.											0.	1.	0.	0.	0.
Impact, recovering						0.								0.	0.	0.	0.
Natural-natural-impact (clearing)	0.	9.												9.	9.	4.	9.
Total	0.	15.				0.							0.	16	16.	7	15.
Impact																	
Natural-impact-river	0.													0.	0.	0.	0.
Natural-natural-impact	0.	6.											0.	7.	7.	3.	6.
Natural-impact (clearing)-impact		1.												1.	1.	0.	1.
Natural-impact (clearing)-river/substrate		0.												0.	0.	0.	0.
Impact, no change						0.								0.	0.	0.	0.
Impact-river/substrate						0.								0.	0.	0.	0.
Impact-recovering-impact						0.								0.	0.	0.	0.
Natural-impact-impact	0.	0.												1.	1.	0.	1.
Total	1.	8.				0.							0.	9	9.	4	9.
														220.	106.		

[a] Definitions of grouped landcover classes:

Impact, no change: originally impacted and remained impacted

Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.

Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.

Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.

Natural-impact-impacted: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)

Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

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Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.
Natural, no change: the 1975 vegetation class was unchanged through the study period.
Natural-impacted (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.
Natural-impacted (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.
Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.
Natural-natural-impacted (cleared): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.
River, unchanged: classified as a river for each year assessed.
Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).
Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.
Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.
Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

[b] Acreage values and percentages were adjusted to exclude classes occurring in the river channel (river, substrate, vegetated bank face, etc.)

Table 6.–Summary of measurement error statistics for selected structures, Kenai River, 1998.

Mean Percent Error	
All structures, trial 1.	-4.2
All structures, substituting trial 2 areas.	-3.5
Repeated structures only.	
Trial 1	-8.4
Trial 2	-4.4
Percent Error Range	-14.1 to 13.0
Structures under estimated	23
Structures over estimated	10

in 1975, expanded throughout the 1980s and 1990s. Recreational use, particularly in the form of power boat activity, likely increased through time, but was considered to be at a much lower level than in Area A. (The Kenai River sport fishery for Chinook salmon, a power boat based fishery, is primarily prosecuted downstream of river mile 21.) Results showed greater mainland bank loss in period 1 (-2.2 acres) than period 2 (-0.1 acres; Table 1 and Figure 2).

The contrary results for Area B (greater bank position loss in period 1 instead of no change or greater loss in period 2) were likely due to problems associated with the 1985 photo set. This photo set was shot in late May using black and white photography. Initially, AeroMap staff thought this format would allow accurate assessment of bank change. However, delineating the bank line location was difficult due to the various shades of gray in the photographs. To further complicate this process, closer scrutiny of the photography revealed that snow and ice were present, mostly in the form of shelf ice along the riverbanks. May of 1985 was also a particularly low discharge period for the Kenai River in comparison to the other years in the study. Discharge was 11,700 cfs for July 6, 1975; 1,800 cfs for May 28, 1985; and 13,400 cfs for June 14, 1998 (USGS 2003). Low water levels made it difficult to discriminate between bank edge and exposed stream substrate in some bank areas, particularly with the presence of shelf ice. It is likely these same problems were present in Area A, but to a lesser degree possibly due to the differences in bank topography. Area A is characterized by generally higher banks (greater than 3 feet high), to include several bluffs. Shelf ice, although present in 1985, was less problematic in determining bank lines. Vegetation along the stream bank in Area A appeared to be composed of a greater percent of tall shrubs and trees which allowed easier determination of bank line (greater contrast with the black and white photography). For Area B, riverbanks were generally less than 3 feet high, having no bluffs. Vegetation was primarily composed of herbaceous plants and short shrubs near the bank edge. The combination of low banks, short nearshore vegetation, exposed substrate, and retention of shelf ice likely made identification of the bank line more problematic in Area B than Area A.

Between areas, it was expected that there would be a greater annual average rate of bank loss (width of bank polygon) in Area A than B for mainland banks for the same period (n.b., since the two areas are different in size (number of river miles) we can only compare annual average rates of change). The relationship was contrary to the expected for period 1 (annual average rate of change in Area A = -2.3 inches/year, Area B = -5.5 inches/year), but the expected for period 2 (annual average rate of change in Area A = -4.9 inches/year, Area B = -0.2 inches/year; Table 1). Again, the problematic 1985 photo set is likely responsible for the inverse relationship for period 1 and may partially misrepresent period 2.

Using these data to evaluate aerial photogrammetry as a tool for determining bank position change, it would be more appropriate to compare overall changes between 1975 and 1998, thus omitting the problematic 1985 photo set. The annual average rate of bank loss (width of bank polygon) for mainland banks was -3.8 inches/year in Area A and -2.5 inches/year in Area B (Table 1). This is the expected relationship between areas, based upon geologic characteristics and human use.

Analysis of changes in bank position gain between periods provided further credence to the problems associated with the 1985 photo set. Summation of gains for periods 1 and 2 should equal that for period 3, but it did not: Area A (4.4 acres + 2.9 acres ≠ 1.5 acres), Area B (0.9 acres + 1.5 acres ≠ 0.2 acres; Table 1). In both cases, gains during period 3 are less than either period 1 or 2.

period 1 or 2. A similar relationship existed for bank position loss. The results for islands further confirm this problem. For example, for Area A, there were -2.2 acres of bank loss in period 1, but 2.0 acres were gained back in period 2 (Table 1). These examples indicate problems with the location of the middle year (1985) bank line with relationship to the other years.

Because of the way we defined the bank position line (top of the bank) it is unlikely that in a 23-year period, or less, that much gain in bank position would be realized. Accretion would tend to occur as deposits along the waterline and would likely not affect the bank line. Therefore, assessed gains in bank position in this project are likely related to bank line location errors and not true accretion that would occur over a longer time period.

When mapping the bank lines, we anticipated the lines to have a specific order: 1975 (furthest offshore), 1985, and 1998 (furthest onshore). This relationship is characterized in the planimetric map in Figure 3 (Slikok Creek area). The enlarged area shows a 4 to 5 foot loss of riverbank between 1975 and 1985 (average of 0.4 to 0.5 ft/yr), and a 4 to 7 foot loss between 1985 and 1998 (average of 0.3 to 0.5 ft/yr). The accuracy of these bank lines is likely fairly good since the bank is taller and there is no shelf ice present in the 1985 photo of this area. The Slikok Creek area was a study site for an on ground shore angler impact study (King and Hansen 1999, 2001, 2002, *In prep a, b*) in which bank loss between 1998 and 2001 was estimated as 3.6 ft (average of 1.2 ft/yr).

The planimetric map in Figure 4 depicts two situations when the bank lines do not occur in the anticipated order. For the lower enlargement, the 1998 bank line lies further offshore than the 1975 bank line. For the upper enlargement, the 1975 and 1998 bank lines are reversed, but approximately the same distance apart. Since the level of accuracy for locating the bank lines is ±12 inches, the difference of 1 to 1.7 feet between the 1975 and 1998 bank lines could mean that there is no change or that 1975 is actually offshore to 1998. Discrepancies at this level logically indicate low or no estimated bank position change. The 1985 bank line may actually be the most problematic in Figure 4 because the bank is relatively short (~3 feet) having herbaceous vegetation near bank edge and there was shelf ice present. In the shore angler impact study, this site had a bank change of zero between 1998 and 2001 (King and Hansen *In prep b*).

The planimetric map in Figure 5 shows a shoreline in Area B in which the 1985 bank line is offshore to the properly ordered 1975 and 1998 bank lines. It is likely the 1985 bank line is similar in location to 1975. The 1998 bank line is probably representative of bank changes occurring as a result of localized human perturbations. Keystrone Drive parallels the right riverbank, providing access to this river reach, but was not built until about 1980, so there was almost no human impact in the late 70s and early 80s. When the road and boat launch were built, this increased access to the river and may have begun to influence bank position at this location. This area is located on a straight channel of the river that is geologically very stable, hence not likely to have high rates of natural erosion. From the early 1990s forward, this area became a very popular shore angler destination. Because of increasing rates of bank erosion attributed to high densities of shore anglers (King and Hansen 2001, 2002, *In prep a and b*), this access was closed to shore angling in 1996, except for the corporate landowner and its employees who were not allowed to stand on the bank while fishing. In Figure 5, bank measurements show greater loss of bank position in proximity to the boat launch and tapering levels of loss as you depart from the launch. This was likely due to higher density of shore anglers and related impacts near the launch. Also, the upstream side of the launch has less bank position change (11.1 ft) compared to the compared to the downstream side (21.9 ft). This can be explained by hydrologic forces having more direct contact with the exposed downstream bank face created by the launch, as well as the presence of shore anglers, both accelerating the erosion rate. Some power boating activity occurs in this area and may contribute to undercutting of banks, but the activity is minimal compared to the number of boats downstream of the Soldotna Bridge (Dorava and Moore 1997). In the shore angler impact study, this site had an average bank loss of –0.7 ft (King and Hansen *In prep b*). The reduced bank loss is largely due to an onsite security officer, present since 1996, who ensured that shore anglers did not fish from the riverbank, minimizing foot traffic along the bank.

LANDCOVER CHANGE

The problematic 1985 photography set likely affected the landcover change analyses, but to a much lesser extent than the analyses of bank position change. This is because only the landcover located in the immediate area of the bank edge was affected. Therefore, trends associated with landcover class changes were actually very good, having a minimal bias related to the bank edge location in 1985.

To better understand vegetation changes as related to development, we combined appropriate landcover classes into two landcover classes: vegetation (tree cover and groundcover) and development (cleared areas, structures, and harbors inside the study limits). For Areas A and B there was a trend for decreasing cover in vegetation with increasing cover related to development (Tables 2 and 3, Figure 9). For Area A the changes in percent cover of vegetation between periods 1 (-5.3%) and 2 (-5.0%) equated to a loss of -10.3% (-36.2 acres) from 1975 to 1998. The percent cover for development in period 1 (4.1%) and period 2 (3.3%) equated to a gain of 7.4% (26.1 acres) from 1975 to 1998. For Area B, the changes in percent cover of vegetation between period 1 (-3.9%) and period 2 (-6.1%) equated to a loss of 10.0% (-10.6 acres). The percent cover for development in period 1 (1.9%) and period 2 (6.8%) equated to a gain of 8.7% (9.2 acres). It should be noted that the slopes of the vegetation and development lines are biased due to the classification of lawns in the groundcover class. If lawns were easily discernable from natural herbaceous cover, then the percent cover of vegetation would be smaller and development would be greater. Nonetheless, the trends for change in cover for vegetation and development are well defined and as expected.

More specifically, we looked at relationships of changes for combined landcover (mainland and island; see also Tables 2 and 3) to see if the changes summed correctly:

- Area A, Period 1:

  Trees (-32.9 acres of change) from an increase in groundcover (14.3 acres) + cleared area (10.4 acres) + structure (2.8 acres) + loss of bank position (4.6 acres) = 31.3 acres of changes

- Area A, Period 2:

  Groundcover (-29.0 acres of changes) from an increase in trees (11.4 acres) + cleared area (4.6 acres) + structure (6.6 acres) + loss of bank position (6.3 acres) = 28.9 acres of changes

- Area B, Period 1:

Trees (-6.9 acres of changes) from an increase in groundcover (2.8 acres) + cleared area (1.7 acres) + structure (0.2 acres) + loss of bank position (2.2 acres) = 6.9 acres of changes

- Area B, Period 2:

  Trees (-7.9 acres of changes) from an increase in groundcover (1.4 acres) + cleared area (4.4 acres) + structure (2.9 acres) + loss of bank position (0.1 acres) = 8.8 acres of changes.

Although these summations do not perfectly balance the total estimated cover changes, they do show expected relationships and adequately account for a high percentage of the change in landcover. For period 1 in area A there was a loss of tree cover with an associated increase in groundcover, cleared areas, and structures. The remaining tree cover loss may be primarily attributed to the transition of tree covered banks into water through loss of bank position. Period 2 in area A was characterized by loss of groundcover due to further land clearing and construction (structures), but there was some increase in tree cover. This is likely due to natural succession of shrubs and saplings to trees or to previously impacted vegetation that was allowed to mature. Cover changes for period 1 in area B were similar to those of period 1 in Area A: initial felling of trees resulting in increased groundcover and cleared areas. But, in contrast, there was a relatively small increase in cover of structures. Period 2 in area B, however, continued to have a loss in tree cover. However, the altered habitat was more rapidly changed to cleared areas and structures rather than the intermittent phase of groundcover.

The trends for rate of change between periods were as expected. Area A had an average -3.3 acre/yr loss of trees during period 1, followed by an average 0.9 acre/yr gain during period 2 (Table 2, Figure 10). For groundcover there was an average gain of 1.4 acre/yr for period 1 and an average loss of -2.2 acre/yr for period 2. The average rate of gain for cleared areas was greater in period 1 (1.0 acre/yr) vs. period 2 (0.4 acre/yr). The average rate of gain for structures was greater in period 2 (0.3 acre/yr) vs. period 1 (0.5 acre/yr). We would expect the felling of trees and greater land clearing to occur in period 1. Often tree removal is not immediately followed by land clearing; hence, there would be a resultant increase in groundcover. We would expect a greater rate of construction to occur in more recent years (period 2) due to increased population and improved road access to the river. For Area B the average rates of change were very similar between periods for trees (-0.6 and –0.7 acre/yr), groundcover (0.3 and 0.1 acre/yr), and cleared areas (0.2 and 0.3 acre/yr; Table 3 and Figure 12). The average rate of change for structures was notably different between periods (0 and 0.2 acre/yr). Loss of trees occurred at a steady rate in both periods. Period 1 had a slightly greater rate of increase in groundcover than did period 2, possibly due to an increase in lawns associated with private residences. The rate of gain for cleared areas remained constant, likely due to driveways and parking associated with increase in land accesses. The rate of gain for structures characterized construction in Area B: lands were primarily cleared and access developed during period 1 and construction occurred during period 2. Figure 10 shows that the average rates of change for all four primary cover classes were much greater in Area A than Area B. Again, this is likely due to Area A's proximity to the population center and earlier development of land access.

We also estimated the rate of change for summed landcover classes (vegetation and development) for each area (Tables 2 and 3, Figure 11). Area A was characterized by a greater average rate of loss of vegetation in period 1 (-1.9 acre/yr) than 2 (-1.4 acre/yr) and a decline in the average rate of gain for development from period 1 (1.4 acre/yr) to period 2 (0.9 acre/yr). Area B was characterized by a slight increase in the average rate of loss of vegetation between periods (period periods (period 1: -0.4 acre/yr, period 2: -0.5 acre/yr) and an increase in the average rate of gain for development between periods (period 1: 0.2 acre/yr, period 2: 0.6 acre/yr). The average rates of change for each landcover class are also greater in area A than B. All of these relationships are what might be expected from the areas selected. One would expect the rates of change to be higher near a population center (Area A) and that over time these rates might begin to diminish due to limited availability of land for further development. Access to Area B increased during the 1980s; therefore, one would expect a trend of increasing rates for loss of vegetation and gain in development, particularly as land accesses improved and the population spread.

LANDCOVER CLASS TRANSITION

The estimates of "actual change" for transition of landcover classes (Tables 4 and 5) represent inflated results for riparian habitat assessment because they include channel classes (river, substrate, vegetated bank face, and shoreline transition). Exclusion of these channel classes more accurately describes riparian habitat (mainland and island) changes. For both areas A and B, approximately 74% (259.4 acres in Area A and 79.6 acres in Area B) of the mainland and island cover showed no impact within the 200 ft study limits (Tables 4 and 5, Figure 12). For area A, 9.7% of the riparian habitat was impacted in 1975 or 1985, but recovering by 1998; and, 15.9% of the riparian habitat was impacted in 1975 and remained impacted in 1998. For area B, 15.8% of the riparian habitat was impacted in 1975 or 1985, but recovering by 1998; and, 9.3% was impacted in 1975 and remained impacted by 1998. Again, these values may reflect the expected changes for the areas selected for analysis. By 1998 much of the available land in these study areas had been developed. Primarily in Area A, there are some large tracts of undeveloped land; some of which are privately owned and others are city, borough, or state lands. This would offset the heavily developed areas near the city of Soldotna, as well as popular areas such as Poacher's Cove and Big Eddy Bend. In Area B, many more parcels appear to be developed as private residences, but there appears to be less clearing and a greater maintenance of "green zones" around these residences. This might explain why approximately 74% of the riparian habitats in both study areas remain without impact.

It is also interesting to note the reversal of percentages between study areas for "impacted" and "impacted, recovering" lands (Tables 4 and 5, Figure 12). The higher percentage of more permanently impacted lands in Area A (15.9%) than Area B (9.3%) may likely be due to the proximity to the population center and the earlier development of these lands; most development in Area B did not begin until the mid 1980s. The higher percentage of recovering lands in Area B (15.8%) than Area A (9.7%) may be more related to the type of development. Initially, the Area B lands were cleared for residences and once construction was final the landowners may have begun efforts to revegetate (such as lawns); whereas, impacted sites in Area A may be more prone to further development or more permanent structures.

MEASUREMENT ERROR

Although the mean percent error of -4.2 (Table 6) was within the acceptable range (±5%) previously determined by AeroMap staff when estimating areas using photogrammetrically derived data, it seemed that a high percent of structures were being underestimated. In an attempt to better understand why areas were more often underestimated, we characterized each measured structure by number of measured sides, number of house stories, number of roof lines, and canopy cover or washout in the photography (Appendix D). We totaled these values for each structure to determine a complexity value. Using these data, we tried to find relationships between high between high percent error and a specific characteristic or the complexity value. Finding no relationship, we took a subset of these structures to re-measure, using simple structures having only 1 house story. Of the 6 structures we re-measured, the percent error was reduced in all cases. However, for structure #30 the percent error remained relatively high (-13%; Appendix D). The overall mean percent error for all structures (substituting trial 2 measurements) was reduced from –4.2 to –3.5 (Table 6). More specifically, for the re-measured structures the mean percent error was reduced from –8.4 in trial 1 to –4.4 in trial 2. This is an indication of measurement error associated with on-ground methods; nonetheless, the photogrammetric estimates still tended to underestimate area. Since we found no relationships between structure characteristics and the percent error for area estimates, the underestimation by the photogrammetrically derived data may be more related to randomness, with a tendency to more often underestimate than overestimate while staying within an acceptable error range (±5%).

CONCLUSION AND RECOMMENDATIONS

As this was a feasibility study, the goal was to determine if the proposed technology using aerial photogrammetry was a reasonably accurate method for measuring riparian habitat changes such that the technology would be a useful tool for resource management. Overall, we found assessment of bank position changes and cover changes to yield meaningful and useful results.

Application of this technology will only be as good as the project design. We quickly learned that selection of appropriate photography is a limiting factor whether assessing bank position or cover changes. The photography sets used for assessment need to be shot at similar altitudes (map scale of 1” = 500’ to 1,500’) and during late spring or early summer such that deciduous foliage is minimized. Although the seasonal timing of the photography is important, it is critical that snow and ice are not present. It is also important that color photography is used, rather than black and white. The presence of snow and ice and the use of black and white photography compromised the ability to accurately assess bank position change and, to a lesser extent, landcover change. Clearly, any photography with upland snow cover would be inappropriate for cover assessment. The presence of snow and ice along the shoreline presented problems with determination of the nearshore cover as well as determination of the bank edge. For higher riverbanks with well defined vegetation lines (tall shrubs and trees) the presence of snow and ice was not as problematic as riverbanks that were shorter and more sloping, having shorter vegetation (herbaceous plants and low shrubs). The ambiguity associated with defining the 1985 bank line in this feasibility study resulted in confusion with interpretation of changes not only in bank position between years, but also, and to a lesser extent, with proper classification of landcover in the nearshore area.

Use of black and white photography for photogrammetrically derived landcover analyses was slightly problematic due to the various shades of gray that created minor challenges in accurately defining boundaries of cover classes, as well as locating the bank edge. Color photography provided more distinguished breaks between the various cover classes, allowing improved accuracy for assessment. However, the black and white photography did not compromise the ability to discern trends in cover change over time. Use of black and white photography more seriously effected determination of the bank edge as related to the presence of snow and ice. For some riverbank locations, the shades of gray associated with vegetation, snow, and ice made it more challenging to accurately identify the bank edge.

The application of this technology for assessing bank position change was acceptable. Because of the problems with the 1985 black and white photography, we were not able to reliably compare bank position changes between periods 1 and 2. But, we do feel confident that measurements were reasonably accurate and provided good trend information for bank position change between 1975 and 1998 for each study area. Results showed the expected relationships based upon geologic history, recreational use, and urban development within each study area over time. Area A had a higher annual average rate of bank position loss than area B.

The application of this technology for assessing landcover change was very acceptable. The ability to define cover class polygons and assess trends in cover change over time was less problematic than measurement of bank position change. The 1985 cover class polygons whose boundaries were located at the bank edge were the most problematic, but this would have caused only minor changes in the total area for these polygons and would have had very little impact on trend analyses. We felt that the trend analyses between periods by individual landcover classes, as well as merged landcover classes (vegetation and development) were representative of cover changes through time, particularly with respect to localized development and proximity to the population center.

The assessment of landcover class transitions provided interesting information as to more specific changes in cover through time. We were able to better quantify how each landcover class polygon, as assessed in 1975, changed between periods. This provided useful information on loss of habitat due to development, but also allowed us to better quantify the amount of habitat that was previously impacted, but currently recovering. Landcover class transition assessment yielded very specific estimates on how change occurred whereas the basic landcover class analyses showed general trends in change. If the intent of the assessment program was to look only at trends, then the landcover class assessment approach would be sufficient; however, if the intent is to specifically track how those changes occurred as well as to quantify amounts of recovering habitat, then it would be advisable to conduct the landcover class transition assessment as well.

Measurement error for bank position and landcover changes seemed reasonable. Our goal was to measure bank position change with an accuracy of 12 inches. Comparisons of bank position change using the proposed technology with bank measurements acquired during the on ground shore angler impact study indicated that aerial photogrammetric assessment provided meaningful and reasonable measurements of bank change. Measurement error for landcover change assessment was acceptable. Based upon prior assessments, AeroMap staff assumed a measurement error of ±5%, which we did achieve. Interestingly, the technology tended to randomly and more often underestimate the area for structures, which was the landcover class we used for checking measurement error. From the perspective of estimating landcover change related to human impacts, it would be preferential to error on the conservative side, rather than overestimate. The importance of this is that if trend analyses were to indicate concern related to increased rates of habitat loss, at best, we would know that this is an underestimate and should warrant further investigation.

Findings of this feasibility study indicate that photogrammetric techniques offer great potential as a resource management tool with:

1. the ability to measure habitat changes (bank position and landcover) by establishing a baseline year determined by available historic aerial photography rather than the baseline year being the current year. This provides the capability of having immediate comparison of habitat changes, rather than having to wait until sometime into the future.
2. a technology that offers the ability to measure bank and landcover changes within acceptable limits of accuracy such that trends in habitat change can be detected. We can quantify the amount of change as well as assess rates of change between periods. This is very useful for resource managers who are trying to better understand habitat changes and if there is need for concern associated with increasing loss or rates of loss of habitat.
3. the ability to conduct landcover class transition analyses, managers can actually estimate amounts of habitat that are recovering from previous human impact. This information may be important in recognizing how local citizens and communities realize and address the importance of maintaining healthy riparian habitat.
4. the capability of assessing cause and effect relationships associated with habitat changes in specific situations. Under the right circumstances it may be possible to determine if a change (such as increased bank erosion or loss of trees) is related to a specific cause (flood, recreational use, urban development, etc.). This type of information could be invaluable for future management of a river and its resources.
5. a technology that can be applied to the development of other research projects. For example, hydrologists may wish to look at the widening of a river. Is this phenomenon occurring at unacceptable rates? Is it occurring in specific locations along a river, such as meandering reaches or inside versus outside of a meander? This type of study might provide useful information regarding human use along the river.
6. resulting information from this type of assessment of a river that would provide very valuable information for developing a watershed management plan. It would allow the local communities to better understand changes occurring along the river, while providing very good graphics to visualize those changes.

While this feasibility study was designed to assess aerial photogrammetry as a tool for measuring riparian habitat changes (bank position and landcover) for any river system, we had a very specific interest in it as a tool for measuring changes along the Kenai River. We feel that with proper project design and input from knowledgeable biologists, this technology would greatly enhance our understanding of riparian habitat changes along the Kenai River. As such we would make the following recommendations for a complete assessment of the Kenai River for the 50 river miles downstream of Skilak Lake:

1. Replace the problematic 1985 black and white photography with a color photo set that has no snow or ice.
2. The study limits for this feasibility study were set at 200 feet from each riverbank. It may be more appropriate to increase the study limits to 300 or 500 feet. This would provide a more meaningful assessment of the riparian zone.
3. If this proves to be an effective monitoring tool, it would also be recommended that new GPS controlled color photography be acquired at 10-year intervals, with the next flight recommended for 2008.

ACKNOWLEDGMENTS

I would like to express my gratitude to those individuals who contributed to this research. The staff at AeroMap U.S., particularly John Ellis and Marcie Compton, were instrumental with the initial assessment, compilation, and mapping of the data, to include the many iterations until we arrived at an acceptable product. I would like to thank the landowners along the Kenai River for their cooperative spirit, allowing us to measure structures on their property. Sandi Seagren, Patti Berkhahn, and Pam Russell assisted with collection of these measurements. I would especially like to thank Tim Haverland for time volunteered to conduct the landcover class transition analyses in ArcView. Pat Hansen provided valuable biometric support and insight into the data analyses.

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FIGURES

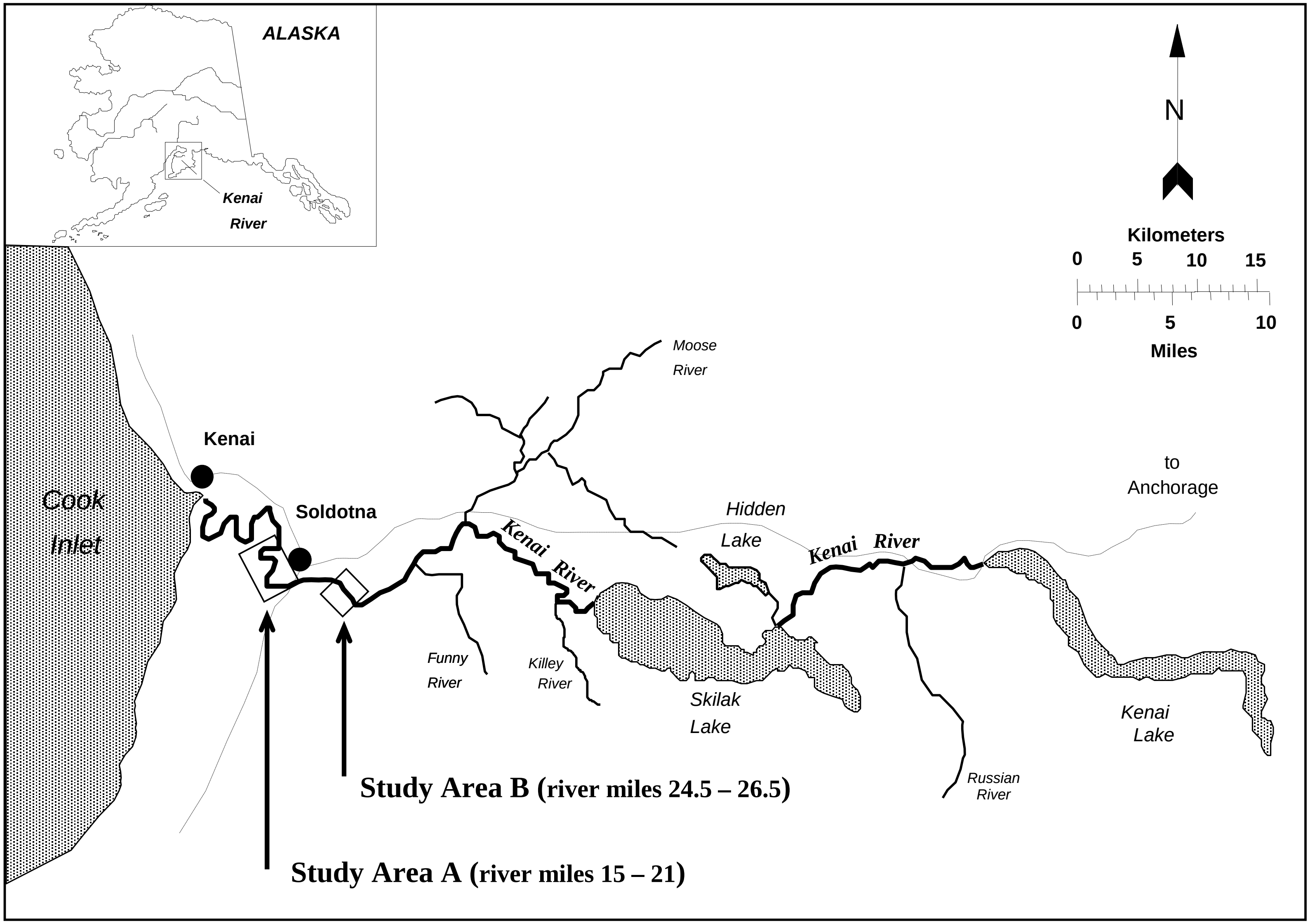


Figure 1.–Map of Kenai River depicting study areas A and B.

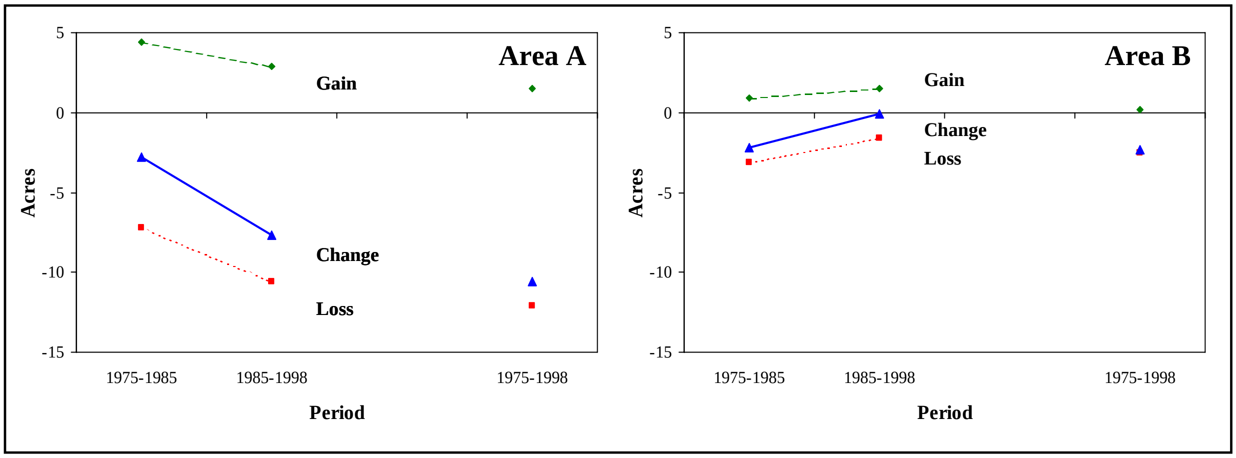


Figure 2.–Bank position gain, loss and change by study area, Kenai River, 1975 – 1985, 1985 – 1998, and 1975 – 1998.

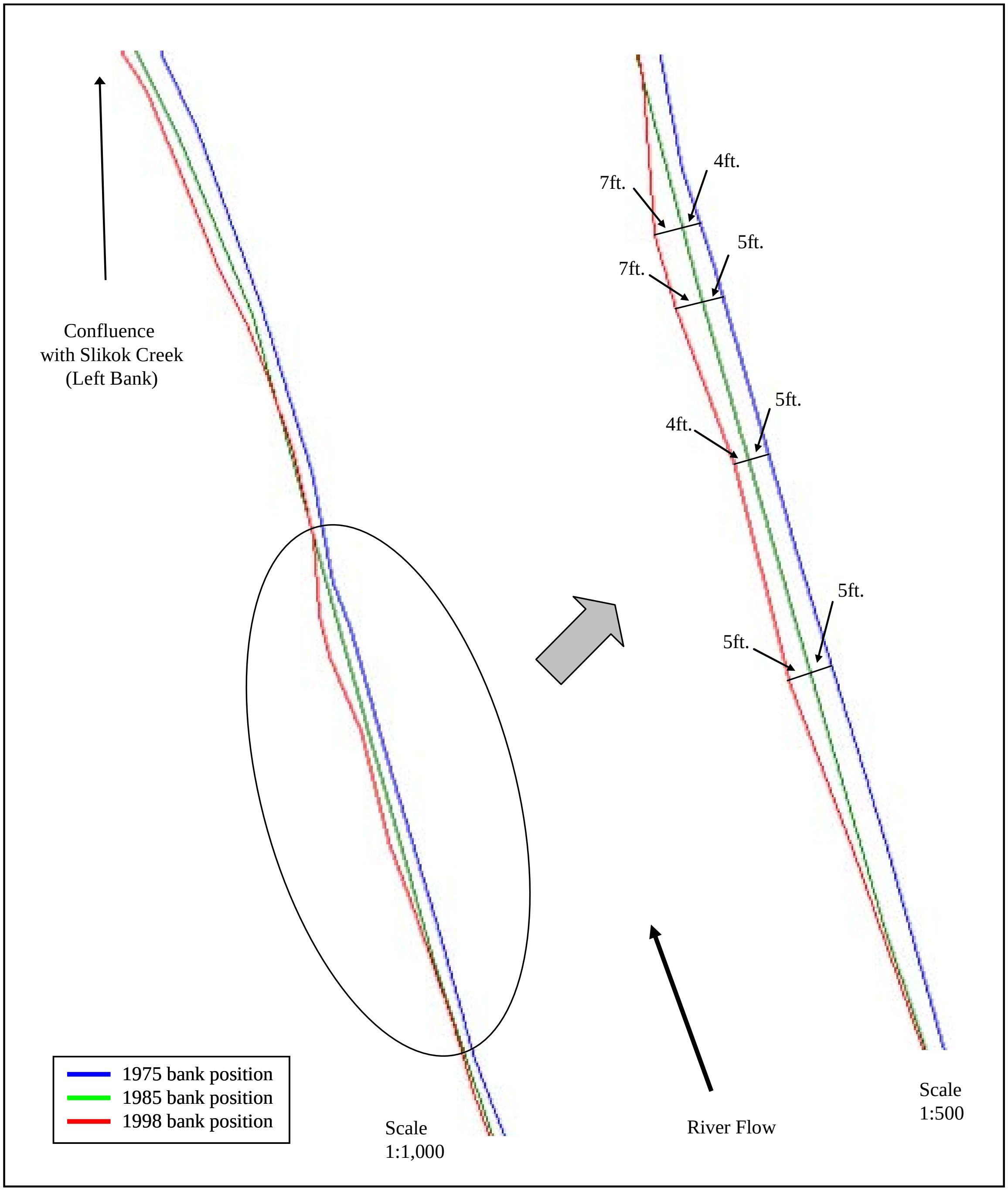


Figure 3.–Bank position lines showing expected order by year, Slikok Creek area, Kenai River.

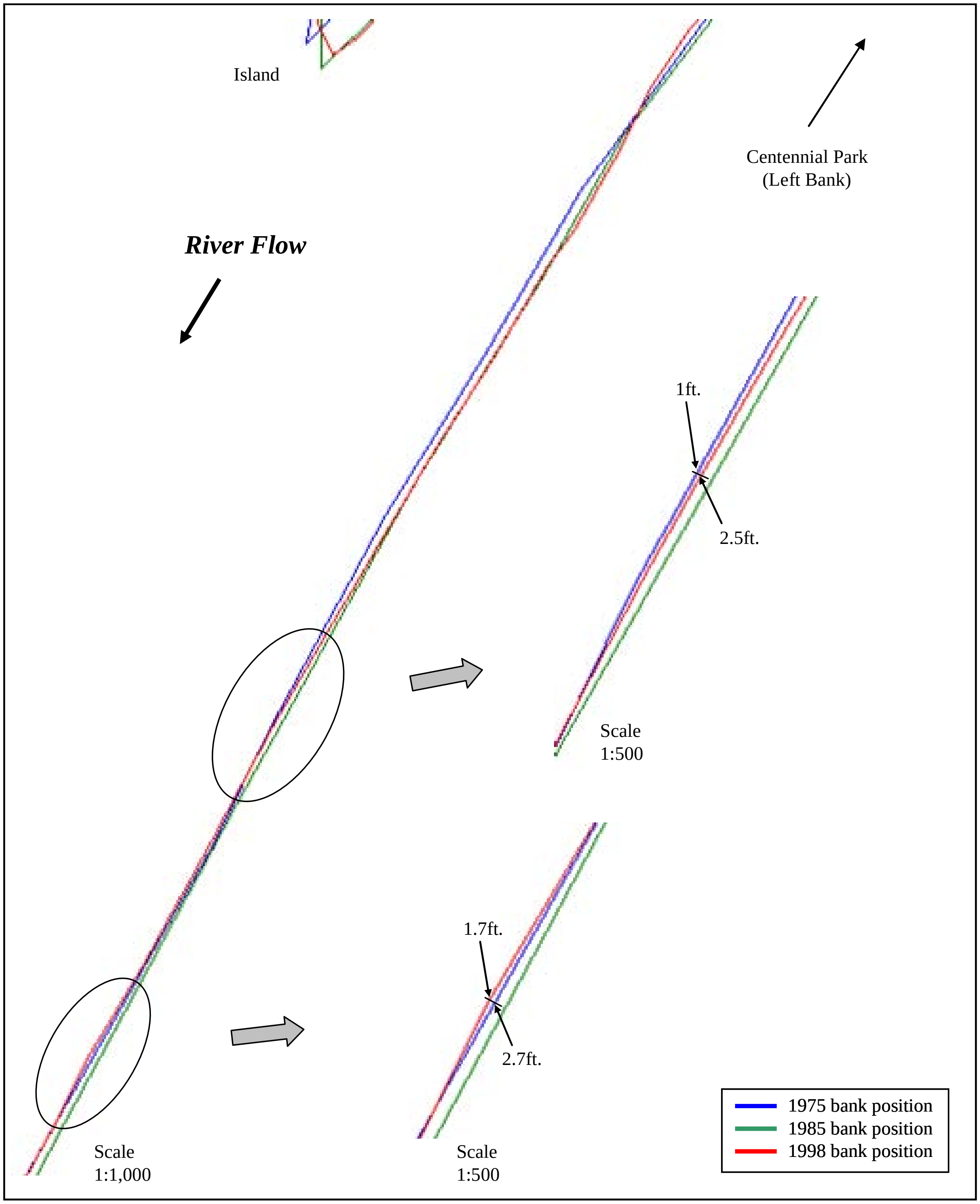


Figure 4.–Bank position lines showing problematic order, near Centennial Park, Kenai River.

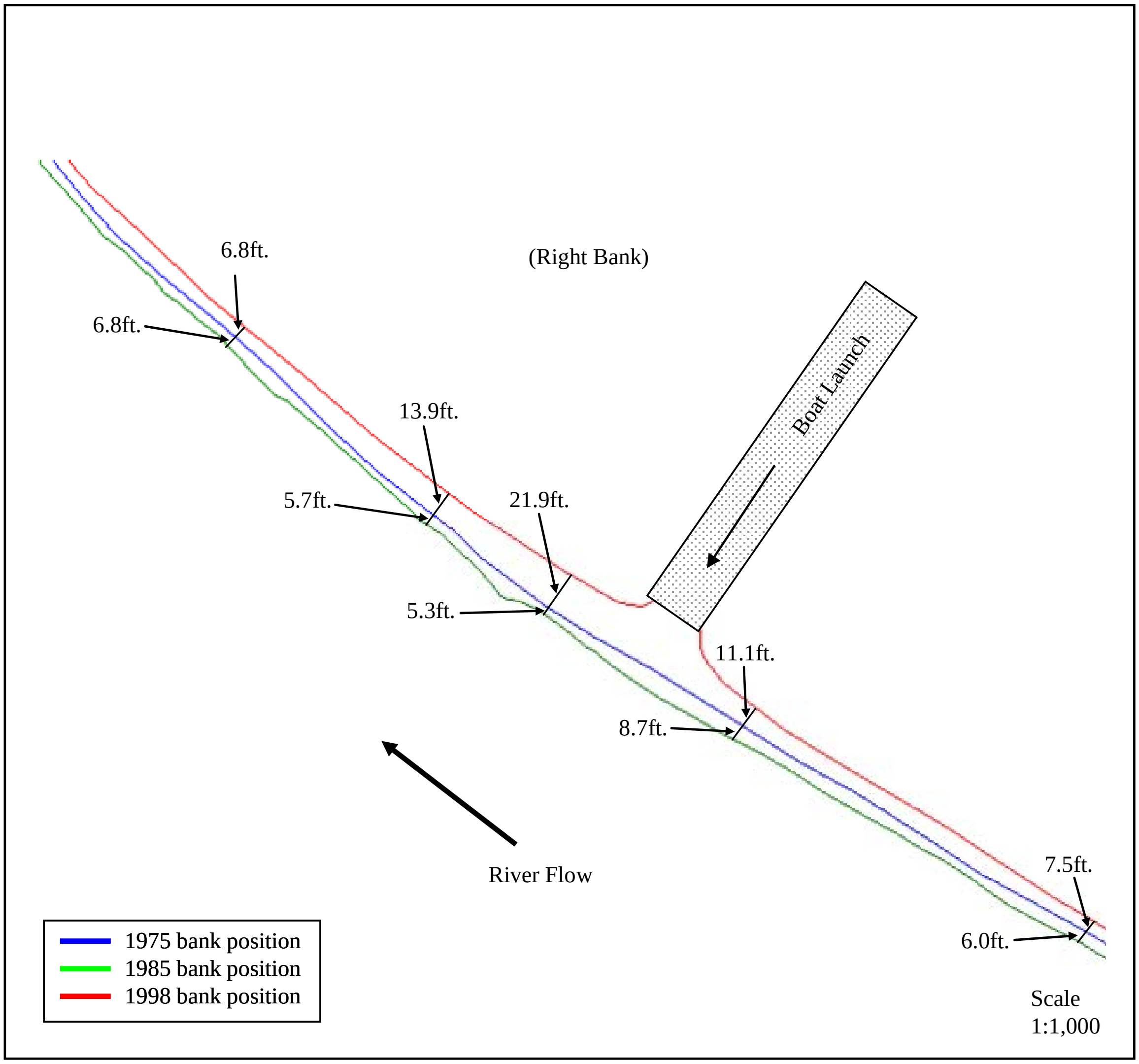


Figure 5.–Bank position lines with only 1985 being problematic, Moose Range Meadows boat launch, Kenai River.

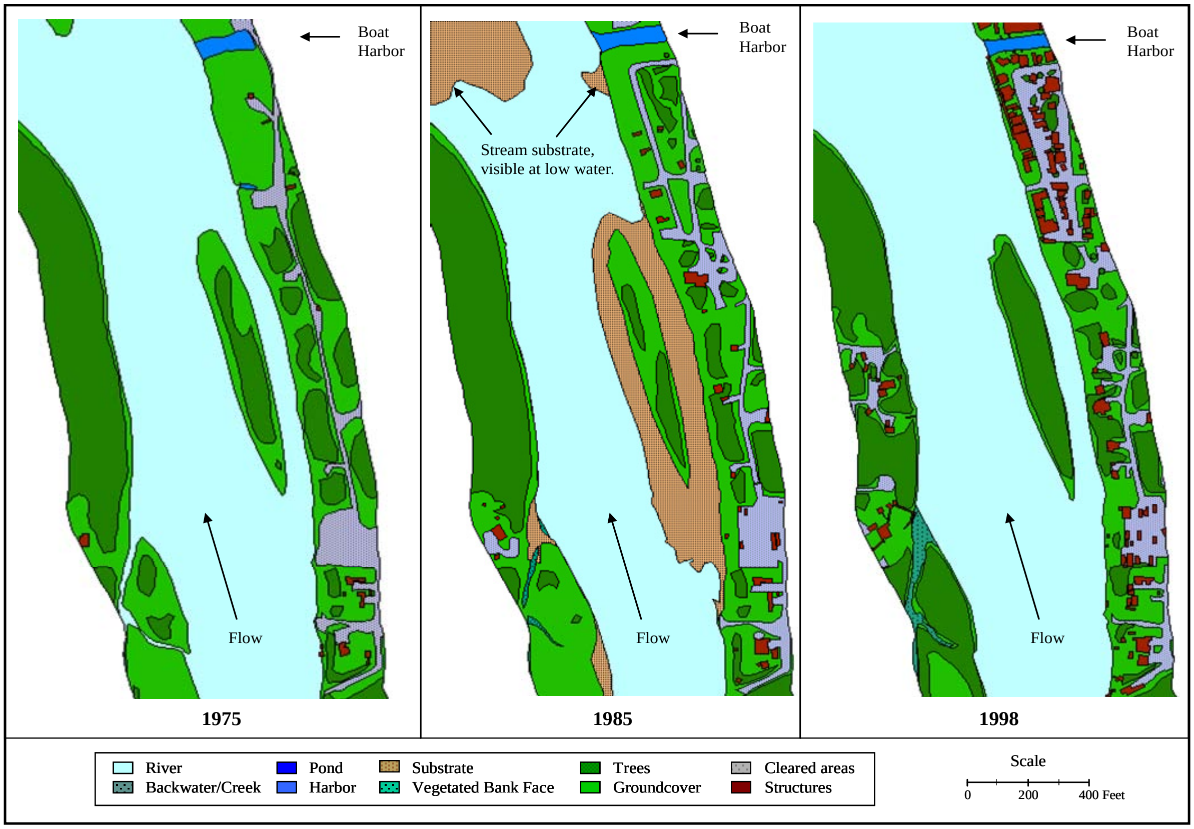


Figure 6.–Cover classification in Area A, near Poacher's Cove area, river mile 17.5, Kenai River, 1975, 1985, and 1998.

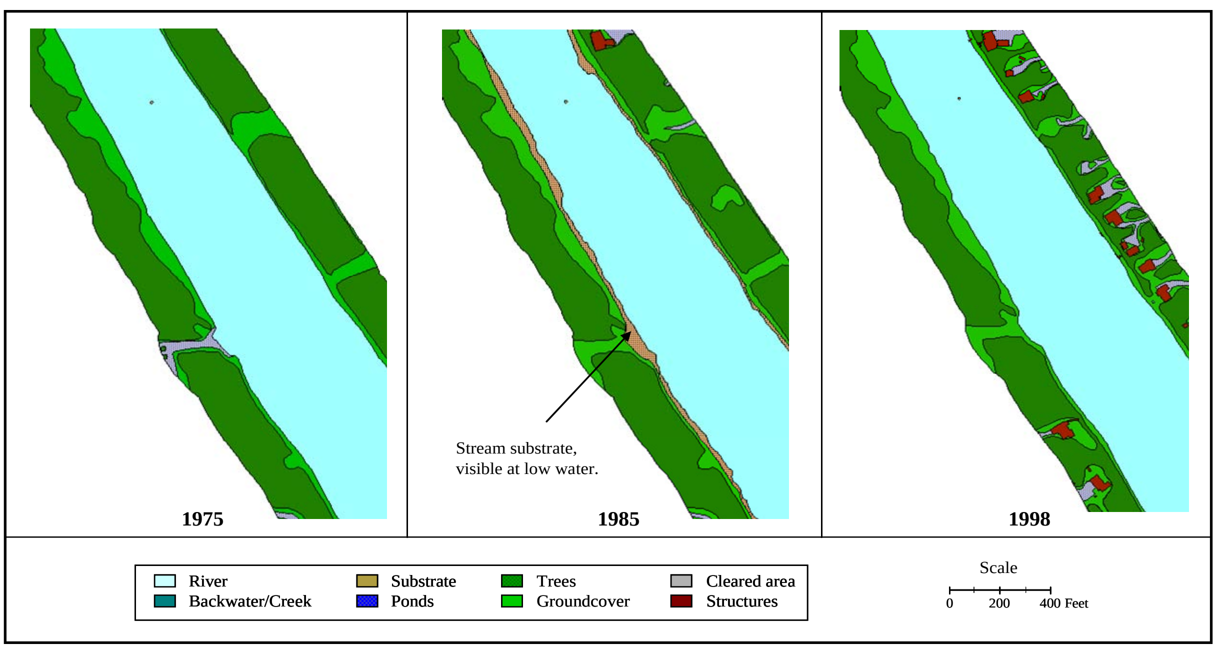


Figure 7.–Cover classification in Area B, near river mile 25, Kenai River; 1975, 1985, and 1998.

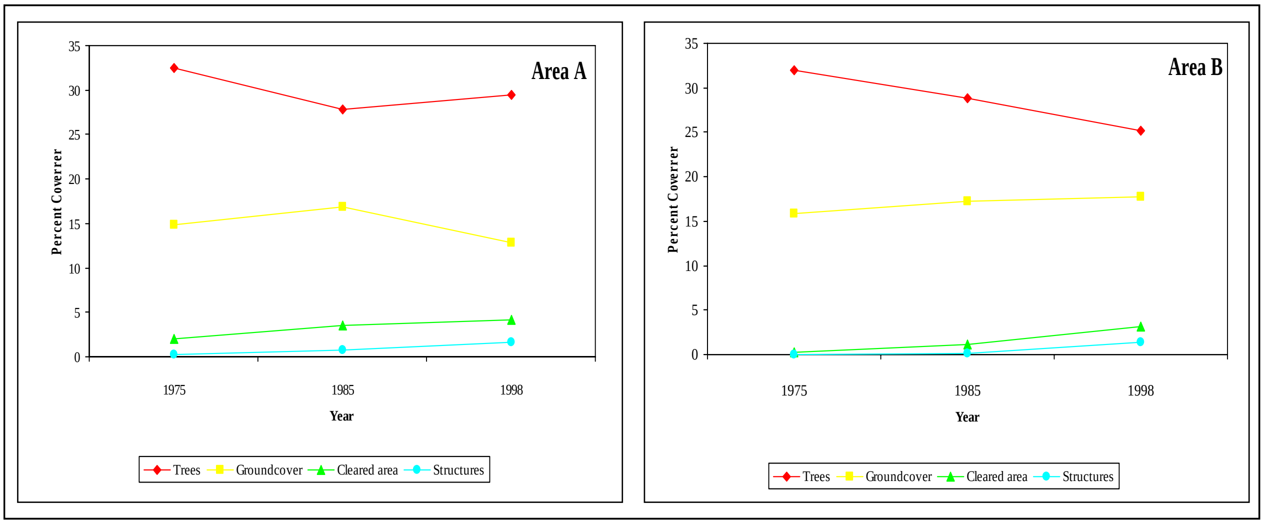


Figure 8.–Percent cover for primary upland cover classes (combined mainland and island) by study area and year, Kenai River. (Percentages based on total area respective to each study area).

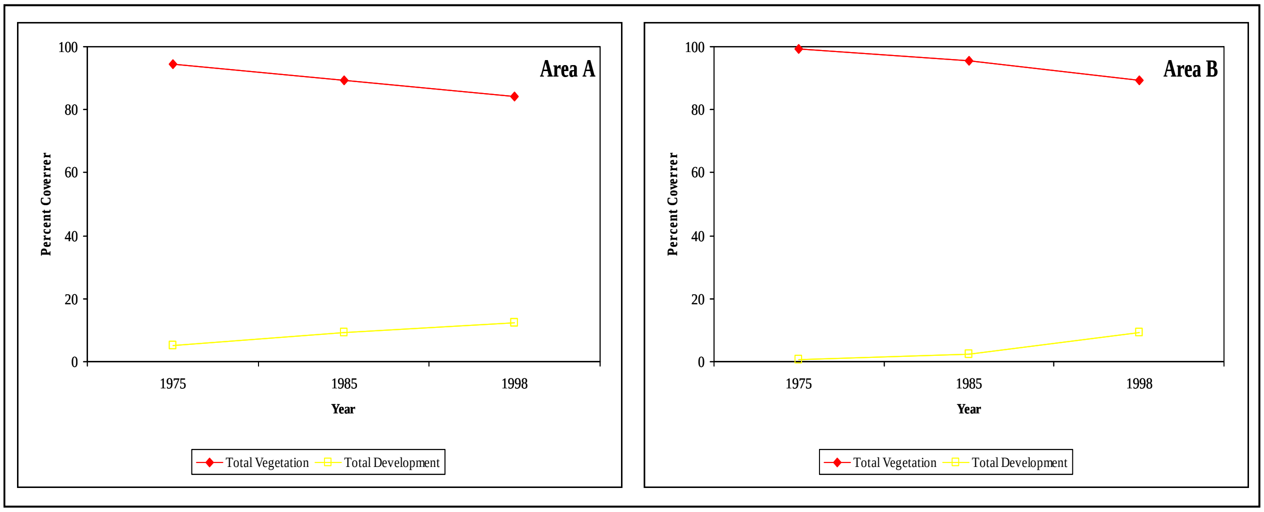


Figure 9.–Percent cover for merged cover classes (total vegetation and total development) by study area and year, Kenai River. (Percentages based on total upland area in 1975 respective to each study area).

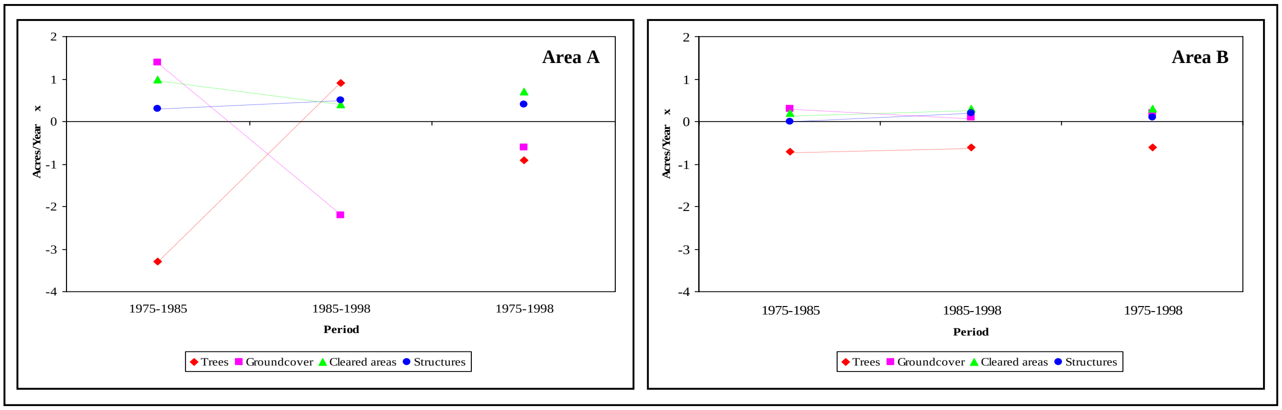


Figure 10.–Annual rate of change for primary cover classes (combined mainland and island) by period and study area, Kenai River.

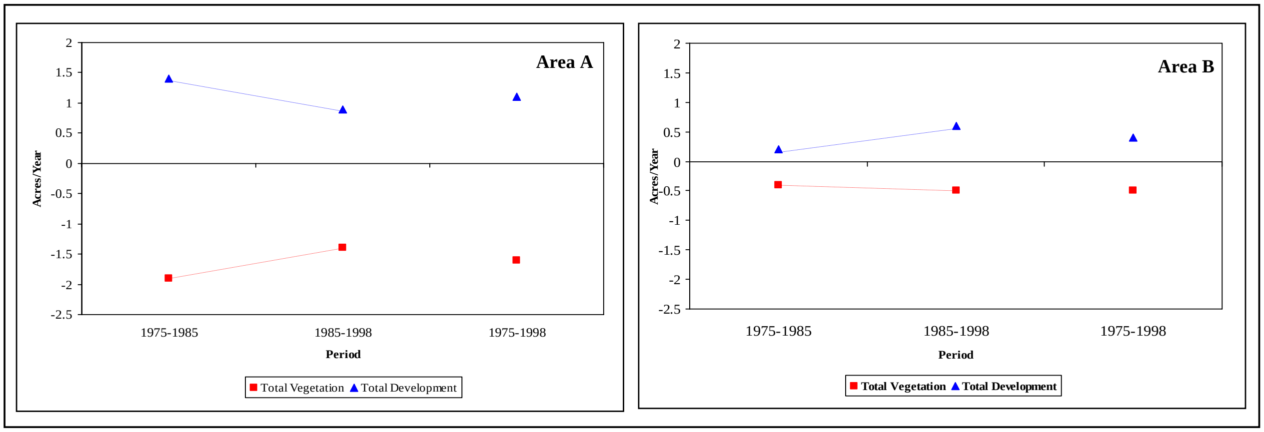


Figure 11.–Annual rate of change for primary cover classes (combined mainland and island) by period and study area, Kenai River. Annual rate of change for merged cover classes (total vegetation and total development) by period and study area, Kenai River.

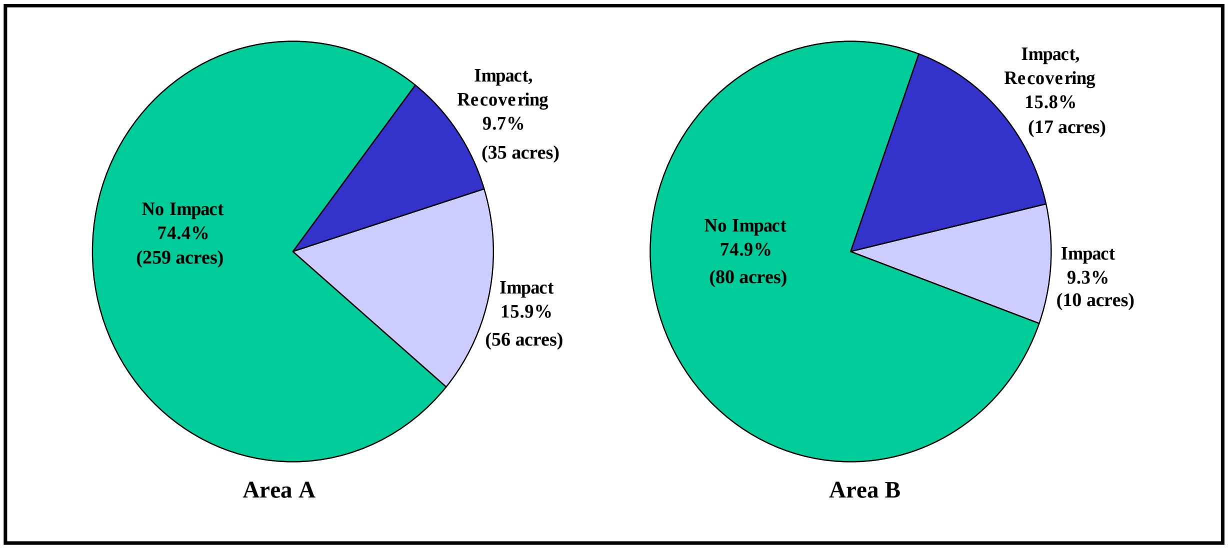
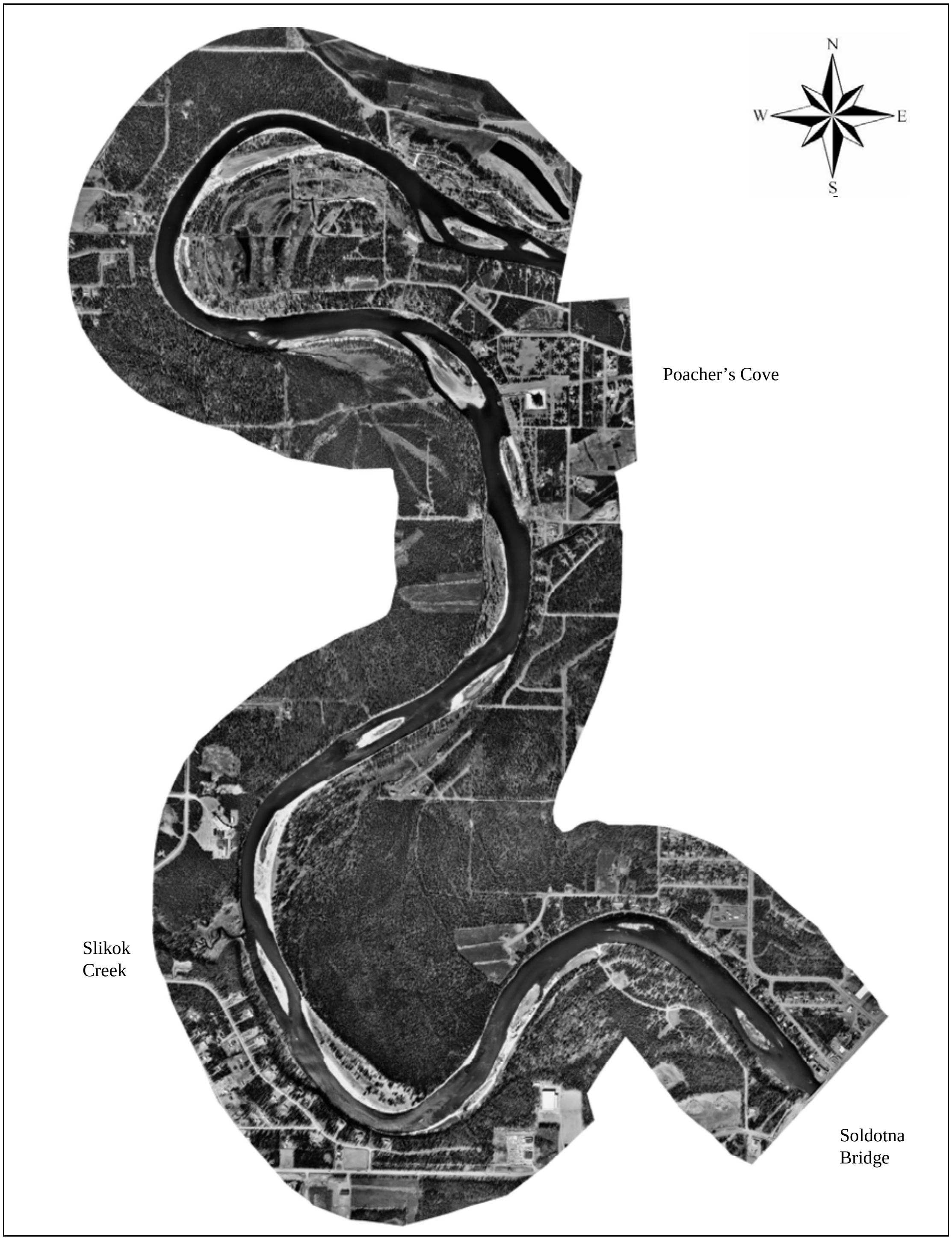


Figure 12.–Status of land cover in 1998 (based upon changes since 1975, using adjusted values from Tables 4 and 5), by study area, Kenai River.

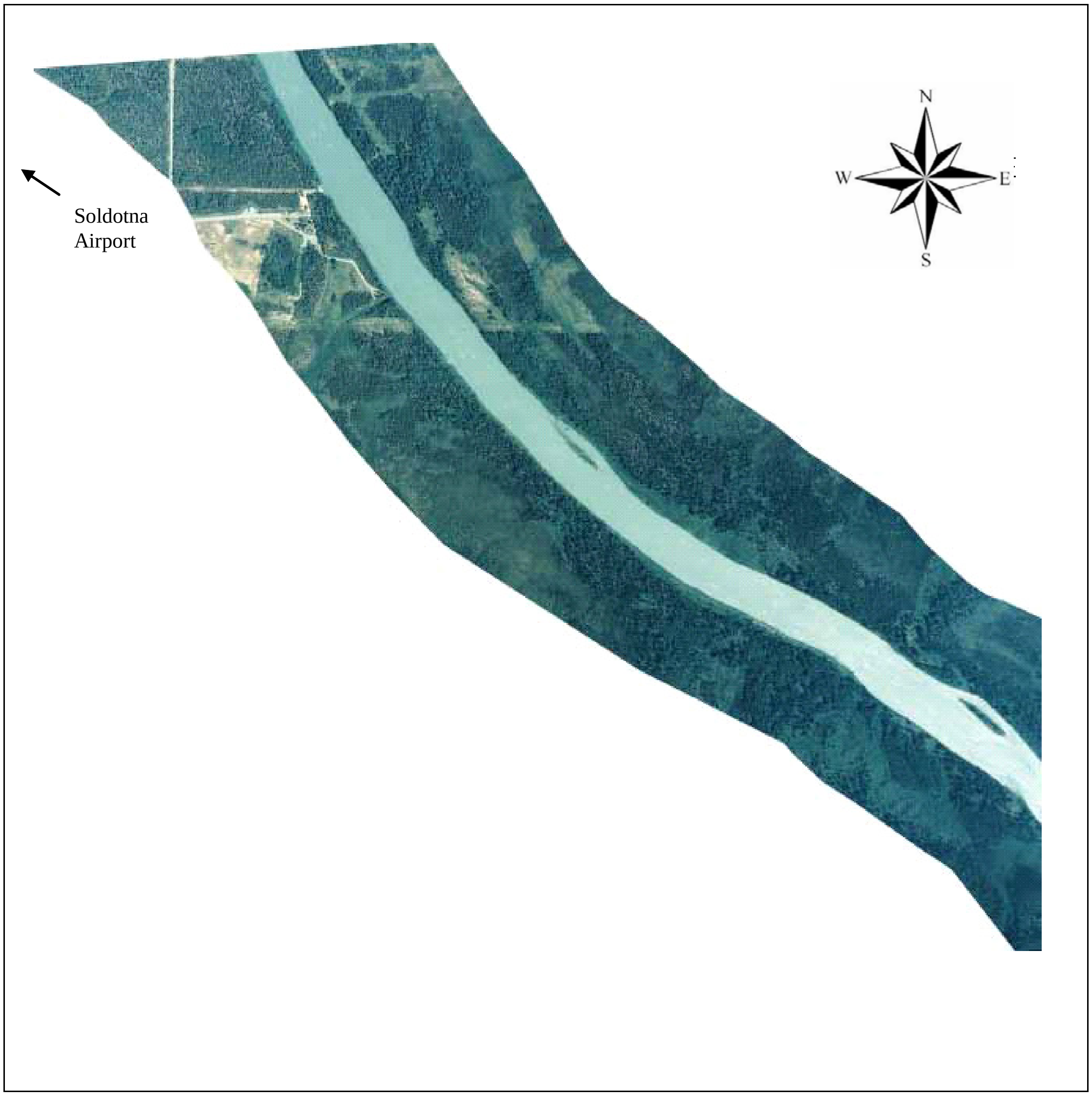
APPENDIX A: ORTHOPHOTOGRAPHY FOR AREAS A AND B

Appendix A1.–Orthophoto of study area A, rivermiles 15 – 21, Kenai River, 1975.

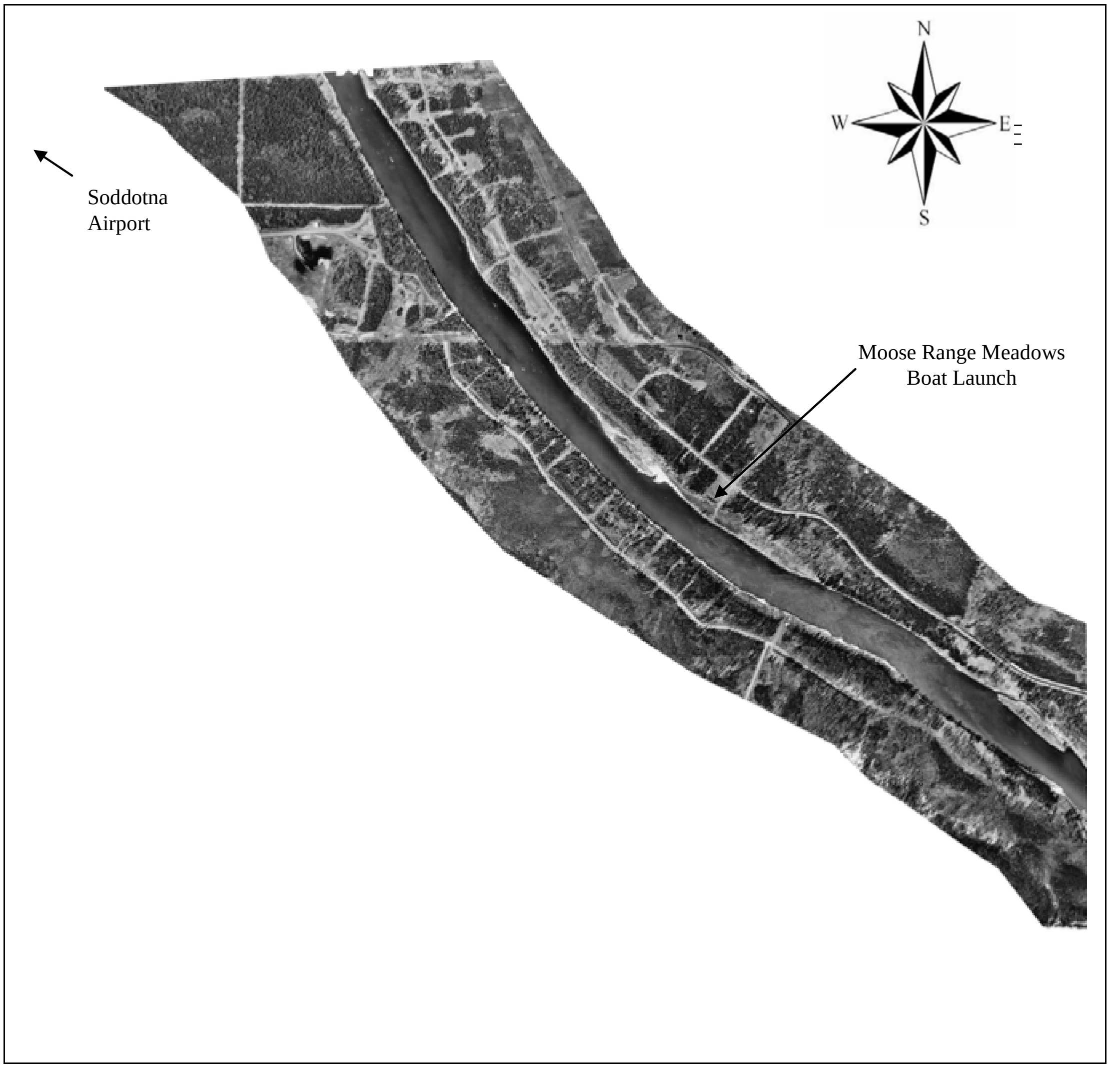


Appendix A2.–Orthophoto of study area A, rivermiles 15 – 21, Kenai River, 1985.

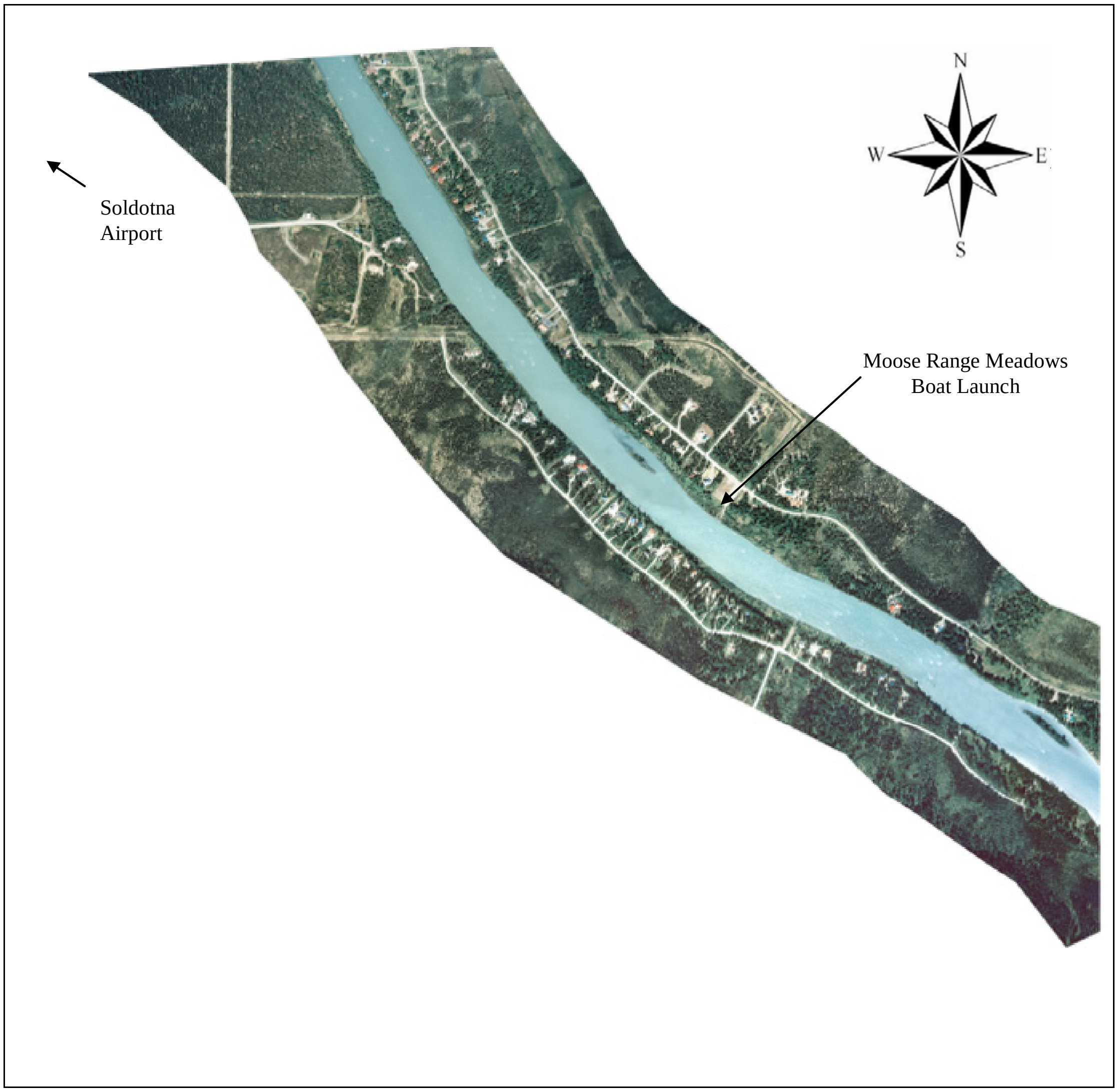
Appendix A3.–Orthophoto of study area A, rivermiles 15 – 21, Kenai River, 1998.



Appendix A4.–Orthophoto of study area B, rivermiles 24.5 – 26.5, Kenai River, 1975.



Appendix A5.–Orthophoto of study area B, rivermiles 24.5 – 26.5, Kenai River, 1985.



Appendix A6.–Orthophoto of study area B, rivermiles 24.5 – 26.5, Kenai River, 1998.

APPENDIX B: FINAL REPORT: KENAI RIVER CHANGE DETECTION PROJECT (AEROMAP U.S.)

Alaska Department of Fish & Game
Division of Sport Fisheries
Final Report

Kenai River Change Detection Project

March 29, 2002

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ABSTRACT

The Kenai River Change Detection project consists of imagery of two separate areas along the Kenai River, each acquired in three individual years. For this pilot project, goals were to distinguish areas where change occurred, as well as to identify the types of change and the most efficient analysis methods.

Imagery derived from multidate aerial photography was analyzed using a variety of methods in an attempt to identify changes both to the river itself, primarily accretion and erosion, and to the landcover in a narrow strip surrounding the river. Photos from 1975 and 1998 were color, and from 1985 were in black and white. This report discusses the different image processing methods employed in an attempt to identify changes to the study areas' landcover.

Following the data preparation and exploration phases, the images were classified using unsupervised* as well as Maximum Likelihood*, Minimum Distance* and Parallelepiped* supervised* classification techniques. The unsupervised classifications were attempted on both original and resampled data. The techniques and results are described below.

Although landcover data were eventually derived, we opted not to use any of the image processing methods described in this document. Subjectively, accuracy and efficiency were highest when photogrammetrically* derived data were processed to create the landcover data. These photo interpretation methods were highly accurate both in regards to location and class, based on visual comparison of the planimetric data to the orthophotos and our experience with past projects, our best estimate is that we have an error rate of plus or minus 5 % on area for these data.

IMAGE PROCESSING

DATA PREPARATION

The photographs from the various years were scanned with 0.5-foot pixels. These images were orthorectified and mosaicked using ERDAS Imagine. Color matching was also performed.

DATA EXPLORATION

The 1975 and 1998 data sets were three-band RGB images, while the 1985 data sets were single-band panchromatic. During the data exploration phase, the dynamic ranges of the imagery were assessed as well as other image statistics. Several preliminary unsupervised classifications were performed to evaluate the data. As all of the images contained only data from the visual spectrum, calculating the standard vegetation indexes* for each image was not possible. Furthermore, the statistical classifiers would not work on the single-channel data.

DATA CLASSIFICATION

Several classification methods were explored throughout the course of this project. In general, the classification steps were 1) set up the classification; 2) examine the data; 3) name the classes; 4) group the classes; 5) reformat the data; 6) filter the data; 7) test the data. Many of the results were too flawed to move beyond naming the classes.

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* See Glossary

Supervised Classification

In addition to the steps described above, the supervised classifications required the identification of training areas in the image. The training areas were very narrowly defined in an effort to create large differences between classes. Many of the final classes were divided into subclasses to enable a wide variety of features, with a broad range of spectral properties, to be eventually grouped into one class. A good example of this would be the Roof class. Area B contained several buildings in 1998 with a variety of roof types and colors. These different roof types needed to be classified separately to prevent statistical class overlaps. Additionally, there are some issues with class mimicry, especially given the limited number of image bands. For example, a blue roof could have similar spectral properties to the river in the visible spectrum.

A variety of supervised classification methods were attempted using the 1975 and 1998 data from Area B. Because Area B is significantly smaller than Area A and is a less complex area overall, the supervised classifications were attempted first on these data sets.

The 1975 data were processed using the Maximum Likelihood classifier with equal prior probabilities. Several other methods were attempted, but the results from the classification proved to be the most robust. Ten training areas representing seven classes were identified in the original image. See Appendix A for the Classification Reports.

Once the data were classified, considerable effort was required refine the final data set. The data were exported to ArcInfo Grid format, filtered to eliminate noise (areas less than 20 square feet), edited, and reclassified to the final nine classes as shown below. The results were still not satisfactory: under visual inspection there was significant confusion between the Forest classes and the Grass classes, Figures 1 and 2.

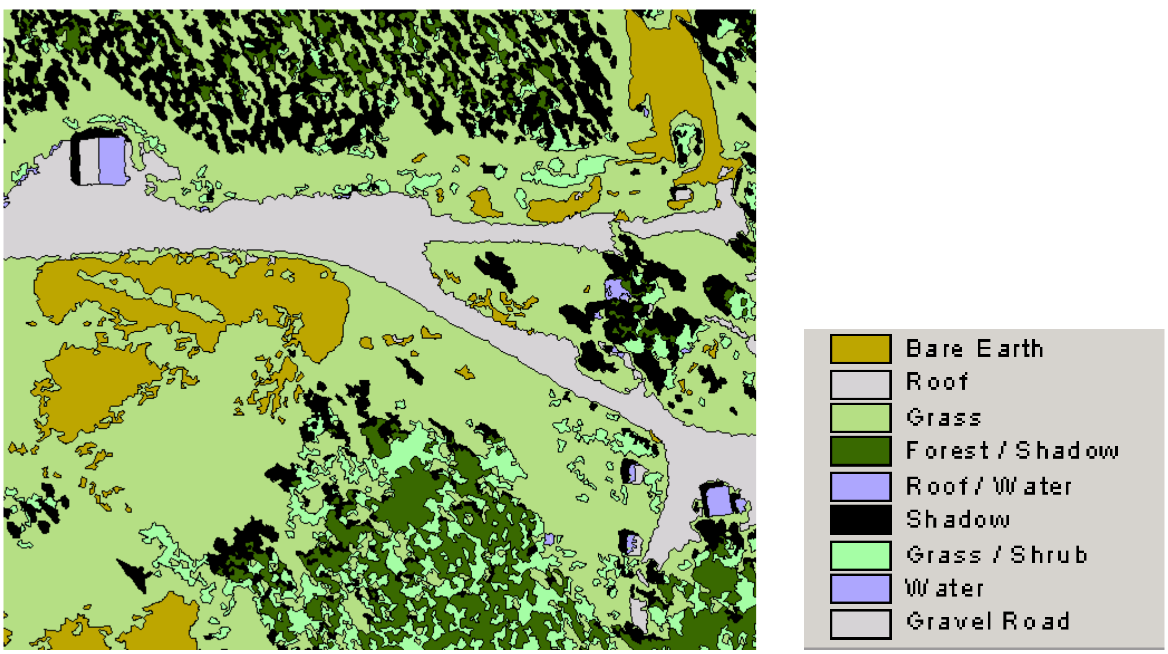


Figure 1.–Sample Supervised Classification Results

Figure 2.–Original Data

The classification procedure followed the same framework for the 1998 data for Area B. The only difference was the classification method used and the number of training classes. The Minimum Distance – Standard Deviation Classifier with 26 classes produced the best results for the 1998 data. The marked increase in the number of classes was required account for the effects of development within the study area. Appendix A summarizes the results.

Class confusion increased with the greater number of classes. The amount of effort involved to achieve even the mediocre accuracy of these results was high. The classification algorithm took over 10 hours of processing time for the 1998 image using a 933 mhz Pentium computer. This does not include the time to define and test the training areas.

Even with careful class delineation, class confusion and the time required to carefully define and test a large number of training areas prevented supervised classification methods from being an efficient and effective method of data analysis. Furthermore, the lack of a preferred supervised classification method did little to engender confidence in creating a consistent method for data analysis.

A primary concern with the supervised classification results was related to the size of the pixels. Classification treats each pixel independently, without regard to its neighbors. When pixel size is small, individual pixels may contain only parts of an object of interest, for example a tree may contain pixels of "sunlight branch" or "shadowed leaves". This "within class variation" makes it difficult to classify a group of pixels as forest. Also of concern in our imagery is that the forested areas are not closed forests. In other words, in many places the trees have visible understory, which further confuses the classes, as grass is a separate class. However, given the purposes of the project, the small grassy areas visible between the trees should still have been classified as forest.

Unsupervised Classification

In light of the lack of success and extensive human component required using the supervised classification techniques, more in-depth attempts were made to evaluate unsupervised classification methods to produce the landcover data. For these efforts the northern portion of the 1975 data for Area A was used. To circumvent some of the difficulties that arise from using such small pixels that one cannot "see the forest for the trees", the data were resampled to three, five and ten foot pixels. This had the added benefit of reducing the long processing times.

The following images illustrate the effects of the resampling. Each image is of the same small area in the Kenai River 1998 orthorectified image. The effects of the resampling are quite obvious, however the results still contain more than ample information for the viewer to discern the various classes.

Figure 3.–Locator Map

Figure 4.–Original Data

Figure 5.–3 Foot Resampled Data

Figure 6.-5 Foot Resampled Data

Figure 7.–10 Foot Resampled Data

Identical unsupervised classifications were performed on the resampled data. The process options* were: auto generate five base classes; 25 maximum iterations; 98% desired unchanged; 20 maximum classes. The algorithms ran much more quickly on the resampled data.

As discussed above, the output of each analysis was individually assessed. Classification results are shown in Appendix A. Classes were named and data sets converted to ArcInfo™ Grid™ format for additional processing. A dataset of 26 randomly placed points across the study area was used to test the final data for each of the three pixel sizes. The landcover at each point in the original image was determined and compared to each data set's results for that location. The results were remarkably similar. The three-foot pixel results contained six errors. Four misclassifications occurred in the five-foot pixel data set. The ten-foot pixel data averaged the previous two data sets with five errors found. While these numbers are not completely out of line with standard error rates for image classification, they do come with a strong *caveat*. Class mimicry and class confusion continued to be a problem, with some classes containing landcover types such as Water, Shadow, and Forest. The complete results for this step and the classes are listed in Appendix A.

Resampling the data appeared to improve the classification results over the supervised classification. However, resampling did not increase the accuracy enough to warrant further investigation of classification techniques. The final data at all three resampling levels still required a significant amount of filtering and editing to reach the accuracy discussed above. As with the results from the supervised classifications, the data were exported to ArcInfo Grid format, reclassified, filtered to remove small areas (less than 20 square feet), and edited.

CONCLUSION

Image classification techniques did not produce the level of results necessary for this project. The level of accuracy required is higher than that possible even with significant human interaction with the classified data. Very narrow training classes for the supervised classifications and large numbers of classes for the unsupervised classifications did not significantly improve the results. Resampling of the data to increase efficiency and to mitigate the effects of the small pixel size was of limited benefit. The classes in the final set of classifications were still too mixed to

* See Glossary

classifications were still too mixed to provide useful data.

Photo interpretation and photogrammetrically derived data are far more efficient and accurate. This method of data creation enables the identification of classes not possible using classification techniques, Vegetated Bank Face, for example. The ability to specify the information necessary for the success of the project is a significant improvement over the limited nature of image classification on three-band imagery. Given the nature of some of the classes identified using photogrammetry, color infrared imagery would not have met the needs of this project either. The Vegetated Bank Face class would not have been possible to differentiate using image processing techniques. See Appendix B for the final results for both areas and all three years.

FUTURE RECOMMENDATIONS

Based on our 2001 pilot project conclusions, where we compared automated image processing and conventional planimetric mapping techniques for classifying topological features, we propose a new method to simplify classification and acreage calculations. Orthophotography is a valuable tool for visually assessing the accuracy of the topological features, but automated classification proved to be inaccurate and excessively time consuming, and although it is possible to overcome some of the major obstacles, we do not recommend the automated classification method at this time. We learned that photogrammetrically compiled planimetric maps yield the best accuracy for feature identification; however, our standard procedures are not suited for the specific nature of this project. We propose a custom version of planimetric mapping to accommodate your requirements. It includes new features and excludes non-relevant features. This method adds all required features and excludes all nonessential features.

AEROTRIANGULATION

The 1998 photography was flown using differential airborne global positioning and key ground surveyed control locations. Aerotriangulation, also referred to as bridging, provides the necessary control for every stereo pair of photos. During the bridging procedure we transfer control from the 1998 photos to the 1985 and 1975 photo sets. Aerotriangulation is a necessary prerequisite for both orthophoto production and planimetric mapping.

ORTHOPHOTO PRODUCTION

Although orthophotography is not a necessary component for feature mapping/classification and acreage calculations, it is invaluable for quality control and analysis. It is also valuable for other uses including sharing with other agencies or as a visual medium for conveying ideas. It provides an understandable visual component. Orthophotography is also very valuable for planning. Beginning in January 2002 we have incorporated automated DEM collection and automated image radiometric adjustment software into our orthophoto production method. This dramatically reduces the orthophoto cost and schedule, while improving the mosaic quality.

Because of the accuracy requirement at the top edge of the bank and at the land/water interface, we recommend adding breaklines to the automated DEM prior to orthophoto production. This is an option you may choose not to use in order to save cost. It is primarily valuable as a quality control issue for checking the bank location, which is sometimes a matter of interpretation. The breaklines are compiled during the planimetric map compilation phase. If you elect to accomplish

accomplish the orthophotos before the planimetric mapping, there would be additional cost related to setting each model twice, once for the breaklines and a second time for the planimetric mapping. We recommend orthophotography for your future program.

PLANIMETRIC MAPPING

In our pilot project planimetric mapping proved to be the most accurate and cost-effective method for compiling thematic data for change detection. Our standard 1”=200’ mapping procedures did not yield the detail required to differentiate some of the vegetation classes or to define the interface between gravel or bare-ground and vegetation. Typically, we do not map movable objects such as trailers or mobile homes, low ground cover, grass, manholes, etc. even when they are visible. These features conflict with National Map Accuracy Standards at this scale. We recommend defining a special mapping scheme for your project that would include all essential items and would exclude non-essential features such as edges of gravel roads and gravel driveways; these are redefined to permit deriving the gravel road/vegetation interface, driveway/vegetation interface, parking area/vegetation interface etc. Prior to project start the mapping scheme should be compiled in detail and reviewed by both parties.

ANALYSIS

Our proposed method of map compilation includes the provision for efficient translation of the AutoCAD files to ArcInfo for analysis. After the data is successfully translated and error-checked, we will calculate the acreage for each of the thematic data classes and prepare a tabular report summary by the theme and year. Shape files, posters, tabular acreage reports, and summary reports are the deliverable products.

DELIVERABLES

The recommended deliverables are a digital copy of the orthophotos in MrSID format, AutoCAD drawing files of the planimetric mapping, ArcView shape files, acreage reports and laminated hard copy posters plotted on glossy paper of the 1998 shape files plus the acreage summary reports.

SUMMARY

These recommendations provide a cost-effective method of compiling change detection information using a reliable and repeatable photogrammetric means. Every effort is made to apply the most up-to-date automation with focus on project specific requirements. Our recommendation saves cost and optimizes value, schedule and accuracy.

APPENDIX A

Area B 1975 - Maximum Likelihood Classification

Means Summary Report[*] for 1975 Area B

Class/Region	Band1	Band2	Band3
Bare Earth	222.971	216.678	189.626
Forest	54.678	117.339	114.837
Forest/Shadow	23.900	69.615	87.547
Grass	115.929	152.027	138.657
Gravel/Road	219.749	228.622	213.267
Outside	2.684	4.824	5.127
River1	198.800	227.027	220.875
River2	147.655	194.655	186.315
Roof	167.043	212.763	218.960
Roof/Water	96.594	165.406	163.311
All	22.819	38.382	39.935

Standard Deviation Summary Report[*] for Area B 1975

Class/Region	Band1	Band2	Band3
Bare Earth	14.421	12.981	14.018
Forest	15.706	16.318	15.604
Forest/Shadow	9.479	21.720	20.756
Grass	30.730	19.753	16.924
Gravel/Road	14.605	11.131	14.373
Outside	13.350	22.453	23.594
River1	20.992	11.348	12.867
River2	14.695	8.722	8.661
Roof	16.216	9.530	8.816
Roof/Water	21.409	16.238	14.399
All	46.389	62.593	61.988

[*] See Glossary

Area Summary Report for Area B 1975

Class/Region	Hectares	Sq. Km	Acres	Sq. Miles
Bare Earth	1.736	0.017	4.29	0.007
Forest	59.518	0.595	147.072	0.230
Forest/Shadow	121.887	1.219	301.19	0.471
Grass	33.595	0.336	83.015	0.130
Gravel Road	2.246	0.022	5.549	0.009
Outside	619.709	6.197	1,531.335	2.393
River1	17.423	0.174	43.054	0.067
River2	25.091	0.251	62.002	0.097
Roof	0.631	0.006	1.560	0.002
Roof/Water	3.290	0.033	8.129	0.013
All	885.126	8.851	2187.194	3.417

Distance Between Class/Region Means* for Area B 1975

	Bare Earth	Forest	Forest/ Shadow	Grass	Gravel/ Road	Outside	River1	River2	Roof	Roof/ Water	All
Bare Earth	0.000	14.043	20.061	7.287	1.952	22.560	2.841	5.581	4.523	8.224	11.171
Forest	14.043	0.000	3.884	3.695	15.171	8.952	13.564	10.829	13.672	4.940	3.646
Forest/ Shadow	20.061	3.884	0.000	7.235	20.848	5.103	17.912	15.708	18.074	8.442	1.575
Grass	7.287	3.695	7.235	0.000	8.578	11.170	8.172	5.317	8.25	1.903	5.081
Gravel/ Road	1.952	15.171	20.848	8.578	0.000	23.871	1.328	6.476	3.789	9.093	11.954
Outside	22.560	8.952	5.103	11.170	23.871	0.000	22.008	21.255	23.381	13.238	1.511
River1	2.841	13.564	17.912	8.172	1.328	22.008	0.000	5.458	2.208	7.857	11.088
River2	5.581	10.829	15.708	5.317	6.476	21.255	5.458	0.000	4.413	4.309	10.368
Roof	4.523	13.672	18.074	8.250	3.789	23.381	2.208	4.413	0.000	7.293	11.716
Roof/Water	8.224	4.940	8.442	1.903	9.093	13.238	7.857	4.309	7.293	0.000	6.197
All	11.171	3.646	1.575	5.081	11.954	1.511	11.088	10.368	11.716	6.197	0.000

* See Glossary

AREA B 1998 - MINIMUM DISTANCE – STANDARD DEVIATION CLASSIFICATION

Means Summary Report[*] for Area B 1998

Class/Region	Band1	Band2	Band3
10-Grass	84.244	95.143	76.495
11-Forest	33.411	33.473	32.152
12-Grass/Scrub	112.318	137.117	121.793
13-Road/Roofs	247.158	248.172	245.721
14-Roof	45.302	90.024	105.178
15-Roof	120.098	192.677	208.103
16-Gravel	226.619	227.844	215.551
17-Gravel	237.039	240.987	233.355
18-Gravel	208.656	212.085	196.935
19-Grass	141.673	142.400	124.726
21-Roofs, Roads, Bare Ground	251.756	254.123	250.926
20-Grass	198.455	196.856	172.216
22-Gravel	218.299	223.478	212.740
23-Roads, Roofs	249.379	245.852	231.557
24-Roofs, some Bare Ground	254.351	195.017	158.182
25-Grass, nearly bare soil	154.539	172.259	148.675
26-Water, Blue Roofs	162.962	204.879	209.189
3-Trees/Some Shrub	112.837	153.410	136.651
4-Bare Ground/Gravel	239.314	232.102	208.502
5-Tree/Grass	49.908	72.345	68.658
6-Water	131.625	179.736	180.847
7-Water/Gravel	204.194	226.857	224.018
8-Tree/Grass/Shrub	79.857	110.536	100.187
9-Grass/Shrub	123.361	146.642	112.974
2-Bare Ground	223.711	216.601	185.430
27-Shadow	62.364	51.220	52.020
All	34.052	40.117	37.232

[*] See Glossary

Standard Deviation Summary Report[*] for Area B 1998

Class/Region	Band1	Band2	Band3
10-Grass	14.419	13.462	9.082
11-Forest	7.502	10.825	11.842
12-Grass/Scrub	14.180	8.387	12.783
13-Road/Roofs	4.204	1.995	3.333
14-Roof	2.802	5.449	8.381
15-Roof	5.757	3.320	4.159
16-Gravel	3.760	3.914	4.855
17-Gravel	6.201	4.211	8.265
18-Gravel	5.665	4.356	6.356
19-Grass	6.834	4.245	6.464
21-Roofs, Roads, Bare Ground	6.041	1.707	6.673
20-Grass	8.517	5.738	8.417
22-Gravel	1.499	2.014	3.022
23-Roads, Roofs	3.771	2.675	6.472
24-Roofs, some Bare Ground	1.233	14.028	17.003
25-Grass, nearly bare soil	22.680	11.464	16.050
26-Water, Blue Roofs	19.598	14.902	19.925
3-Trees/Some Shrub	18.871	7.094	7.282
4-Bare Ground/Gravel	6.579	5.122	7.179
5-Tree/Grass	8.653	12.862	11.497
6-Water	7.486	4.375	5.211
7-Water/Gravel	12.848	7.416	9.440
8-Tree/Grass/Shrub	13.422	13.553	11.005
9-Grass/Shrub	13.181	5.474	6.182
2-Bare Ground	10.745	9.316	11.903
27-Shadow	7.175	14.095	15.635
All	58.54	67.646	63.637

[*] See Glossary

Area Summary Report for Area B 1998

Class/Region	Hectares	Sq. Km	Acres	Sq. Miles
10-Grass	13.595	0.136	33.594	0.052
11-Forest	35.608	0.356	87.989	0.137
12-Grass/Scrub	22.489	0.225	55.571	0.087
13-Road/Roofs	0.392	0.004	0.969	0.002
14-Roof	0.127	0.001	0.313	0.000
15-Roof	0.085	0.001	0.209	0.000
16-Gravel	0.882	0.009	2.180	0.003
17-Gravel	2.027	0.020	5.008	0.008
18-Gravel	1.370	0.014	3.385	0.005
19-Grass	1.660	0.017	4.102	0.006
21-Roofs, Roads, Bare Ground	3.897	0.039	9.630	0.015
20-Grass	4.029	0.040	9.957	0.016
22-Gravel	0.128	0.001	0.317	0.000
23-Roads, Roofs	0.838	0.008	2.071	0.003
24-Roofs, some Bare Ground	0.030	0.000	0.074	0.000
25-Grass, nearly bare soil	30.385	0.304	75.083	0.117
26-Water, Blue Roofs	32.089	0.321	79.294	0.124
3-Trees/Some Shrub	7.644	0.076	18.888	0.030
4-Bare Ground/Gravel	1.465	0.015	3.619	0.006
5-Tree/Grass	33.355	0.334	82.422	0.129
6-Water	6.427	0.064	15.881	0.025
7-Water/Gravel	3.803	0.038	9.397	0.015
8-Tree/Grass/Shrub	49.388	0.494	122.040	0.191
9-Grass/Shrub	7.092	0.071	17.524	0.027
2-Bare Ground	3.669	0.037	9.067	0.014
27-Shadow	28.881	0.289	71.366	0.112
All	885.126	8.851	2187.194	3.417

Distance Between Class/Region Means* for Area B 1998 – Page 1

	10-Gra	11-Fore	12-Gras Scru	13-Road Roo	14-Ro	15-Ro	16-Grav	17-Grav	18-Grav	19-Gra
10-Grass		8.26	6.09	47.49	6.97	26.20	33.86	31.05	25.96	10.59
11-Forest	8.26		15.16	68.83	10.70	38.8	52.91	47.43	41.95	24.4
12-Grass/ Scrub	6.09	15.16		37.44	12.81	15.86	25.24	24	18.40	3.12
13-Road/ Roofs	47.49	68.83	37.44		80.41	35.12	11.65	3.95	18.01	48.86
14-Roof	6.97	10.70	12.81	80.41		35.11	65.65	57.8	49.6	24.71
15-Roof	26.20	38.8	15.86	35.12	35.11		24.94	23.84	16.4	21.20
16-Gravel	33.86	52.91	25.24	11.65	65.65	24.94		4	6.39	31.35
17-Gravel	31.05	47.43	24	3.95	57.8	23.84	4		9.68	31.29
18-Gravel	25.96	41.95	18.40	18.01	49.6	16.4	6.39	9.68		22.48
19-Grass	10.59	24.4	3.12	48.86	24.71	21.20	31.35	31.29	22.48	
21-Roofs, Roads, Bare Ground	43.8	65.51	37.12	3.52	76.10	35.07	13.0	5.94	18.9	48.83
20-Grass	18.97	32.44	12.61	22.1	37.57	12.76	10.65	12.74	4.78	14.78
22-Gravel	45.99	74.87	34.4	19.79	95.93	35.50	3.90	9.53	6.22	41.69
23-Roads, Roofs	39.26	61.03	32.00	3.25	76.8	33.29	8.69	2.94	14.30	40.81
24-Roofs, some Bare Ground	41.51	74.33	34.46	15.68	113.1	50.73	15.01	10.73	17.81	39.53
25-Grass, nearly bare soil	9.45	17.68	4.68	22.75	17.6	8.54	13.68	14.15	8.79	4.99
26-Water, Blue Roofs	13.38	20.71	8.71	13.00	21.89	4.39	8.02	8.33	4.5	10.97
3-Trees/ Some Shrub	9.65	18.93	2.61	36.76	14.36	15.31	23.62	23.32	16.60	3.67
4-Bare Ground / Gravel	28.15	44.00	21.5	9.2	54.24	21.60	2.97	3.76	6.79	27.08
5-Tree/ Grass	3.61	4.98	9.47	55.60	4.37	29.06	42.7	38.25	32.98	16.57
6-Water	19.29	31.33	10.26	34.68	28.70	6.99	22.43	22.51	14.23	13.05
7-Water/ Gravel	22.47	33.13	16.19	8.93	36.6	12.22	3.46	4.58	4.38	20.80
8-Tree/ Grass/ Shru	2.64	9.8	3.88	42.11	6.14	20.62	30.58	28.10	22.9	8.23
9-Grass/ Shrub	8.23	19.67	1.90	45.55	16.54	21.6	29.55	28.77	21.36	2.8
2-Bare Ground	18.78	30.79	13.74	12.54	37.91	14.22	4.40	6.41	2.44	16.69
27-Shadow	4.3	4.44	10.5	56.84	7.4	29.71	43.79	39.33	34.0	17.87
All	2.99	0.30	5.72	26.64	4.02	15.35	20.11	18.11	15.9	9.16

* See Glossary

Distance Between Class/Region Means* for Area B 1998 – Page 2

	21-Roof Roads, Ba	20-Gras	22-Grav	23-Road Roo	24-Roof some Ba	25-Gras nearly ba	26-Wate Blue Roo	3-Tree Some Shru	4-Ba Ground	5-Tre Gras
10-Grass	43.8	18.97	45.99	39.26	41.51	9.45	13.38	9.65	28.15	3.61
11-Forest	65.51	32.44	74.87	61.03	74.33	17.68	20.71	18.93	44.00	4.98
12-Grass/ Scrub	37.12	12.61	34.4	32.00	34.46	4.68	8.71	2.61	21.5	9.47
13-Road/ Roofs	3.52	22.1	19.79	3.25	15.68	22.75	13.00	36.76	9.2	55.60
14-Roof	76.10	37.57	95.93	76.8	113.18	17.6	21.89	14.36	54.24	4.37
15-Roof	35.07	12.76	35.50	33.29	50.73	8.54	4.39	15.31	21.60	29.06
16-Gravel	13.0	10.65	3.90	8.69	15.01	13.68	8.02	23.62	2.97	42.7
17-Gravel	5.94	12.74	9.53	2.94	10.73	14.15	8.33	23.32	3.76	38.25
18-Gravel	18.9	4.78	6.22	14.30	17.81	8.79	4.5	16.60	6.79	32.98
19-Grass	48.83	14.78	41.69	40.81	39.53	4.99	10.97	3.67	27.08	16.57
21-Roofs, Roads, Bare Ground		22.36	21.65	4.8	14.91	22.5	13.22	35.71	9.84	52.12
20-Grass	22.36		12.5	17.37	17.28	4.82	4.05	10.61	9.68	24.90
22-Gravel	21.65	12.5		16.7	28.09	17.82	10.76	31.62	7.26	60.53
23-Roads, Roofs	4.8	17.37	16.7		11.09	18.65	12.12	30.05	5.41	49.50
24-Roofs, some Bare Ground	14.91	17.28	28.09	11.09		18.96	18.80	29.69	8.23	63.56
25-Grass, nearly bare soil	22.5	4.82	17.82	18.65	18.96		4.22	3.1	11.84	12.57
26-Water, Blue Roofs	13.22	4.05	10.76	12.12	18.80	4.22		8.25	7.41	15.91
3-Trees/ Some Shrub	35.71	10.61	31.62	30.05	29.69	3.1	8.25		19.95	12.30
4-Bare Ground / Gravel	9.84	9.68	7.26	5.41	8.23	11.84	7.41	19.95		35.41
5-Tree/ Grass	52.12	24.90	60.53	49.50	63.56	12.57	15.91	12.30	35.41	
6-Water	34.65	9.13	30.83	30.67	40.50	4.07	4.91	8.73	19.44	22.76
7-Water/ Gravel	9.96	7.43	3.94	7.82	13.98		3.50	15.74	4.34	26.20
8-Tree/ Grass/ Shrub	39.55	16.57	42.43	36.26	43.5	7.49	11.15	6.32	25.48	4.89
9-Grass/ Shrub	43.63	14.0	39.04	36.6	33.24	5.15	11.08	3.75	24.92	12.38
2-Bare Ground	12.43	4.00	5.00	8.84	8.83	6.71	4.57	12.18	3.83	24.45
27-Shadow	54.01	25.98	62.06	51.14	65.66	13.4	16.23	13.64	36.53	2.5
All	25.2	12.30	28.17	23.14	26.66	6.75	8.04	7.32	16.73	1.74

* See Glossary

Distance Between Class/Region Means* for Area B 1998 – Page 3

	6-Wat	7-Water/ Grav	8-Tree/ Gras Shru	9-Grass/ Shru	2-Bare Groun	27-Shado	A
10-Grass	19.29	22.47	2.64	8.23	18.78	4.3	2.99
11-Forest	31.33	33.13	9.8	19.67	30.79	4.44	0.30
12-Grass/ Scrub	10.26	16.19	3.88	1.90	13.74	10.5	5.72
13-Road/ Roofs	34.68	8.93	42.11	45.55	12.54	56.84	26.64
14-Roof	28.70	36.6	6.14	16.54	37.91	7.4	4.02
15-Roof	6.99	12.22	20.62	21.6	14.22	29.71	15.35
16-Gravel	22.43	3.46	30.58	29.55	4.40	43.79	20.11
17-Gravel	22.51	4.58	28.10	28.77	6.41	39.33	18.11
18-Gravel	14.23	4.38	22.9	21.36	2.44	34.0	15.9
19-Grass	13.05	20.80	8.23	2.8	16.69	17.87	9.16
21-Roofs, Roads, Ba Ground	34.65	9.96	39.55	43.63	12.43	54.01	25.2
20-Grass	9.13	7.43	16.57	14.0	4.00	25.98	12.30
22-Gravel	30.83	3.94	42.43	39.04	5.00	62.06	28.17
23-Roads, Roofs	30.67	7.82	36.26	36.6	8.84	51.14	23.14
24-Roofs, some Ba Ground	40.50	13.98	43.5	33.24	8.83	65.66	26.66
25-Grass, nearly bare so	4.07		7.49	5.15	6.71	13.4	6.75
26-Water, Blue Roofs	4.91	3.50	11.15	11.08	4.57	16.23	8.04
3-Trees/ Some Shrub	8.73	15.74	6.32	3.75	12.18	13.64	7.32
4-Bare Ground / Gravel	19.44	4.34	25.48	24.92	3.83	36.53	16.73
5-Tree/ Grass	22.76	26.20	4.89	12.38	24.45	2.5	1.74
6-Water		12.69	14.86	13.76	11.79	23.68	12.23
7-Water/ Gravel	12.69		19.28	20.20	4.18	26.71	12.88
8-Tree/ Grass/ Shrub	14.86	19.28		5.53	16.97	5.92	3.70
9-Grass/ Shrub	13.76	20.20	5.53		15.44	13.99	7.45
2-Bare Ground	11.79	4.18	16.97	15.44		25.3	11.64
27-Shadow	23.68	26.71	5.92	13.99	25.3		1.50
All	12.23	12.88	3.70	7.45	11.64	1.50	

* See Glossary

AREA A 1975 – 3-FOOT PIXELS

Means Summary Report[*] for Area A 1975 – 3-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest Shadow / Dark Ground	67.055	27.516	42.693
2-Forest Shadow / Dark Water	70.926	39.800	56.915
3-Forest Shadow / Dark Ground	75.739	54.838	68.772
4-Grass/Shrubs	81.759	71.263	80.388
5-Grass/Shrubs	89.368	86.957	91.697
6-Grass/Shrubs	99.515	101.876	102.368
7-Grass/Shrubs	113.013	116.490	112.284
8-Shallow Water/Forest Shadow	119.871	132.382	127.522
9-Grass/Shrubs	141.401	134.127	121.268
10-Water	153.347	170.301	161.088
11-Water	165.913	181.796	170.955
12-Water	139.554	151.898	143.642
13-Bare Ground	164.693	154.806	136.705
14-Bare Ground	185.606	174.732	152.695
15-Shallow Water	180.826	193.781	183.633
16-Roads/Bare Ground	206.525	193.992	168.923
17-Roads/Bare Ground	221.055	211.784	187.224
18-Roads/Bare Ground	237.348	229.224	204.381
19-Outside/Roofs	254.995	254.994	254.976
All	159.427	153.761	155.474

[*] See Glossary

Standard Deviation Report[*] for Area A 1975 – 3-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest Shadow / Dark Ground	4.952	5.885	6.688
2-Forest Shadow / Dark Water	5.381	5.548	5.901
3-Forest Shadow / Dark Ground	5.692	5.936	6.554
4-Grass/Shrubs	6.049	5.935	6.840
5-Grass/Shrubs	6.641	5.646	7.101
6-Grass/Shrubs	7.710	5.842	7.524
7-Grass/Shrubs	9.353	6.027	7.373
8-Shallow Water/Forest Shadow	7.575	6.562	7.018
9-Grass/Shrubs	7.515	7.264	7.767
10-Water	6.417	4.701	6.413
11-Water	5.914	4.115	5.994
12-Water	7.536	6.477	7.308
13-Bare Ground	7.964	6.822	7.823
14-Bare Ground	8.742	6.542	7.994
15-Shallow Water	6.760	5.012	7.510
16-Roads/Bare Ground	7.887	6.074	8.184
17-Roads/Bare Ground	8.403	5.539	8.175
18-Roads/Bare Ground	7.569	6.590	8.709
19-Outside/Roofs	0.218	0.210	0.702
All	78.415	86.718	81.429

[*] See Glossary

Area Summary Report* for Area A 1975 – 3-Foot Pixels

Class/Region	Hectares	Sq. Km	Acres	Sq. Miles
1-Forest Shadow / Dark Ground	37.196	0.372	91.914	0.144
2-Forest Shadow / Dark Water	54.850	0.548	135.536	0.212
3-Forest Shadow / Dark Ground	50.488	0.505	124.759	0.195
4-Grass/Shrubs	49.653	0.497	122.694	0.192
5-Grass/Shrubs	47.398	0.474	117.124	0.183
6-Grass/Shrubs	40.975	0.410	101.251	0.158
7-Grass/Shrubs	31.122	0.311	76.905	0.120
8-Shallow Water/Forest Shadow	14.209	0.142	35.111	0.055
9-Grass/Shrubs	12.331	0.123	30.471	0.048
10-Water	20.101	0.201	49.671	0.078
11-Water	24.968	0.250	61.698	0.096
12-Water	9.309	0.093	23.003	0.036
13-Bare Ground	7.168	0.072	17.712	0.028
14-Bare Ground	6.049	0.060	14.948	0.023
15-Shallow Water	14.856	0.149	36.709	0.057
16-Roads/Bare Ground	5.734	0.057	14.170	0.022
17-Roads/Bare Ground	6.770	0.068	16.728	0.026
18-Roads/Bare Ground	4.965	0.050	12.269	0.019
19-Outside/Roofs	239.972	2.400	592.984	0.927

All 678.114 6.781 1675.655 2.618

* See Glossary

Distance Between Class/Region Means* for Area A 1975 - 3-Foot Pixels

	1-Fores Shadow Dar Groun	2-Fores Shadow Dark Wate	3-Fores Shadow Dar Groun	4-Gras /Shrub	5-Gras /Shrub	6-Gras /Shrub	7-Gras /Shrub	8-Shallo Wate /Fores Shado	9-Gras /Shrub	10-Wate	11-Wate	12-Wate	13-Bar Groun	14-Bar Groun	15 Wate	16 Roads Bar Groun	17 Roads Bar Groun	18 Roads Bar Groun	19 Outside Roof	A
1-Forest Shadow / Dark Ground		3.21	6.2	9.64	13.11	16.09	19.15	22.63	23.09	36.0	41.55	27.48	28.53	33.37	41.46	39.55	44.65	47.66	290.32	8.7
2-Forest Shadow / Dark Water	3.21		3.35	6.87	10.45	13.60	16.77	20.36	20.83	33.71	39.16	25.30	26.31	31.23	39.33	37.39	42.57	45.65	279.62	8.1
3-Forest Shadow / Dark Ground	6.2	3.35		3.42	6.85	9.97	13.09	16.57	17.34	29.07	34.16	21.37	22.61	27.33	34.69	33.24	38.11	41.30	256.22	6.98
4-Grass/ Shrubs	9.64	6.87	3.42		3.3	6.57	9.72	13.18	14.19	25.14	29.9	17.95	19.3	23.98	30.85	29.73	34.44	37.74	237.18	6.00
5-Grass/ Shrubs	13.11	10.45	6.85	3.3		3.	6.53	9.99	11.15	21.5	26.15	14.75	16.22	20.82	27.35	26.43	31.08	34.42	219.47	5.05
6-Grass/ Shrubs	16.09	13.60	9.97	6.57	3.		3.21	6.58	7.80	17.33	21.60	11.16	12.6	17.05	23.06	22.34	26.80	30.09	194.79	3.98
7-Grass/ Shrubs	19.15	16.77	13.09	9.72	6.53	3.21		3.39	4.4	13.40	17.33	7.76	9.0	13.34	19.03	18.32	22.66	25.89	170.32	2.9
8-Shallow Water/ Fores Shadow	22.63	20.36	16.57	13.18	9.99	6.58	3.39		2.98	9.73	13.51	4.56	6.78	10.87	15.71	15.83	19.91	23.54	159.03	2.19
9-Grass/ Shrubs	23.09	20.83	17.34	14.19	11.15	7.80	4.4	2.98		8.55	11.9	3.94	4.64	8.96	13.96	13.7	17.85	21.28	144.06	1.73
10-Water	36.0	33.71	29.07	25.14	21.5	17.33	13.40	9.73	8.55		3.67	4.64	4.67	4.53	7.16	8.75	12.81	17.05	128.95	0.89
11-Water	41.55	39.16	34.16	29.9	26.15	21.60	17.33	13.51	11.9	3.67		8.13	7.14	4.03	4.01	6.43	10.29	14.77	118.52	1.66
12-Water	27.48	25.30	21.37	17.95	14.75	11.16	7.76	4.56	3.94	4.64	8.13		3.	6.77	10.79	11.45	15.38	19.12	135.51	0.95

* See Glossary

Distance Between Class/Region Means* for Area A 1975 - 3-Foot Pixels – Page 2.

	1-Fore Shadow Dar Groun	2-Fore Shadow Dark Wate	3-Fore Shadow Dar Groun	4-Gras /Shrub	5-Gras /Shrub	6-Gras /Shrub	7-Gras /Shrub	8-Shallo Wate /Fore Shado	9-Gras /Shrub	10-Wate	11-Wate	12-Wate	13-Bar Groun	14-Bar Groun	15 Wate	16 Road Bar Groun	17 Road Bar Groun	18 Road Bar Groun	19 Outside Roof	A
13-Bare Ground	28.53	26.31	22.61	19.3	16.22	12.6	9.0	6.78	4.64	4.67	7.14	3.		4.38	9.31	9.00	13.16	16.67	119.44	0.77
14-Bare Ground	33.37	31.23	27.33	23.98	20.82	17.05	13.34	10.87	8.96	4.53	4.03	6.77	4.38		5.23	4.43	8.55	12.15	95.33	1.33
15-Shallow Water	41.46	39.33	34.69	30.85	27.35	23.06	19.03	15.71	13.96	7.16	4.01	10.79	9.31	5.23		3.98	6.35	10.34	90.92	2.41
16-Roads/ Bare Ground	39.55	37.39	33.24	29.73	26.43	22.34	18.32	15.83	13.7	8.75	6.43	11.45	9.00	4.43	3.98		4.19	8.03	74.68	2.63
17-Roads/ Bare Ground	44.65	42.57	38.11	34.44	31.08	26.80	22.66	19.91	17.85	12.81	10.29	15.38	13.16	8.55	6.35	4.19		4.07	55.10	3.7
18-Roads/ Bare Ground	47.66	45.65	41.30	37.74	34.42	30.09	25.89	23.54	21.28	17.05	14.77	19.12	16.67	12.15	10.34	8.03	4.07		32.98	4.85
19-Outside/ Roofs	290.32	279.62	256.22	237.1	219.47	194.79	170.32	159.03	144.06	128.95	118.52	135.51	119.44	95.33	90.92	74.68	55.10	32.98		35.66
All	8.75	8.1	6.98	6.00	5.05	3.98	2.9	2.19	1.73	0.89	1.66	0.95	0.77	1.33	2.41	2.63	3.7	4.85	35.66	

* See Glossary

AREA A 1975 – 5-FOOT PIXELS

Means Summary Report[*] for Area A 1975 – 5-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest (Shadow)	67.08	27.568	42.782
2-Water	70.931	39.88	57.038
3-Water	75.797	54.983	68.849
4-Grass/Shrub	81.794	71.361	80.465
5-Grass/Shrub/Forest (Shadow)	89.377	87.002	91.712
6- Grass/Shrub/Forest (Shadow)	99.495	101.896	102.426
7-Dark Bare Ground	112.725	117.272	113.256
8-Grass/Shrub	130.525	133.125	124.287
9-Water	153.311	170.292	161.071
10-Water	165.837	181.735	170.898
11-Water	139.829	151.37	142.999
12-Bare Ground	163.551	153.116	134.975
13-Bare Ground	185.349	174.628	152.639
14-Water	180.764	193.769	183.604
15-Bare Ground/Road	206.224	193.636	168.566
16-Road/Some Bare Ground	220.846	211.497	186.909
17-Road/Some Bare Ground	237.198	229.135	204.277
18-Outside/Roofs	254.995	254.994	254.975
All	159.424	153.761	155.475

[*] See Glossary

Standard Deviation Summary Report[*] for Area A 1975 – 5-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest (Shadow)	4.973	5.89	6.689
2-Water	5.364	5.555	5.906
3-Water	5.687	5.916	6.546
4-Grass/Shrub	6.054	5.926	6.827
5-Grass/Shrub/Forest (Shadow)	6.648	5.642	7.101
6- Grass/Shrub/Forest (Shadow)	7.695	5.834	7.526
7-Dark Bare Ground	9.109	6.553	8.114
8-Grass/Shrub	10.584	6.645	8.153
9-Water	6.388	4.683	6.419
10-Water	5.926	4.112	5.987
11-Water	7.941	6.610	7.697
12-Bare Ground	8.087	7.867	8.781
13-Bare Ground	8.696	6.507	7.984
14-Water	6.737	5.005	7.529
15-Bare Ground/Road	7.908	6.062	8.129
16-Road/Some Bare Ground	8.439	5.574	8.163
17-Road/Some Bare Ground	7.633	6.592	8.722
18-Outside/Roofs	0.220	0.213	0.714
All	78.413	86.712	81.418

[*] See Glossary

Area Summary Report for Area A 1975 – 5-Foot Pixels

Class/Region	Hectares	Sq. Km	Acres	Sq. Miles
1-Forest (Shadow)	37.505	0.375	92.677	0.145
2-Water	54.956	0.550	135.799	0.212
3-Water	50.391	0.504	124.520	0.195
4-Grass/Shrub	49.388	0.494	122.041	0.191
5-Grass/Shrub/Forest (Shadow)	47.215	0.472	116.672	0.182
6- Grass/Shrub/Forest (Shadow)	40.986	0.410	101.278	0.158
7-Dark Bare Ground	33.410	0.334	82.557	0.129
8-Grass/Shrub	22.575	0.226	55.785	0.087
9-Water	20.016	0.200	49.462	0.077
10-Water	24.908	0.249	61.550	0.096
11-Water	9.913	0.099	24.496	0.038
12-Bare Ground	8.186	0.082	20.228	0.032
13-Bare Ground	6.037	0.060	14.919	0.023
14-Water	14.906	0.149	36.833	0.058
15-Bare Ground/Road	5.710	0.057	14.110	0.022
16-Road/Some Bare Ground	6.851	0.069	16.930	0.026
17-Road/Some Bare Ground	5.013	0.050	12.388	0.019
18-Outside/Roofs	239.836	2.398	592.648	0.926
All	677.804	6.778	1674.89	2.617

Distance Between Class/Region Means* for Area A 1975 - 5-Foot Pixels

	1-Fore (Shadov	2- Wat	3- Wat	4-Gras Shru	5-Gras Shru	6- Gras Shru	7-Dar Ba	8-Gras Shru	9- Wat	10- Wat	11-Wat	12-Ba Grour	13-Ba Grour	14 Wat	15-Ba Groun	16-Roa Some Ba	17-Roa Some Ba	18-Outsid Roo	A
1-Forest (Shadow)		3.21	6.30	9.65	13.10	16.09	18.60	21.97	36.03	41	26.88	26.76	33.37	41.4	39.44	44.43	47.49	288.0	8.73
2-Water	3.21		3.36	6.88	10.44	13.59	16.31	19.79	33.72	39.12	24.74	24.66	31.25	39.31	37.31	42.39	45.54	277.7	8.10
3-Water	6.30	3.36		3.42	6.84	9.97	12.78	16.20	29.11	34.15	20.91	21.22	27.36	34.71	33.18	37.97	41.2	254.6	6.98
4-Grass/ Shrub	9.65	6.88	3.42		3.3	6.56	9.54	12.97	25.16	29.94	17.54	18.15	23.99	30.85	29.65	34.29	37.64	235.5	6.00
5-Grass/ Shrub Forest	13.10	10.44	6.84	3.3		3	6.46	9.95	21.54	26.12	14.40	15.19	20.83	27.3	26.35	30.9	34.32	217.9	5.05
6- Grass/ Shrub/ Forest	16.09	13.59	9.97	6.56	3		3.25	6.69	17.35	21.59	10.88	11.79	17.07	23.08	22.28	26.69	30.03	193.6	3.98
7-Dark Bare Ground	18.60	16.31	12.78	9.54	6.46	3.25		3.30	12.79	16.57	7.15	8.16	12.94	18.29	17.73	21.84	25.09	164.8	2.84
8-Grass/ Shrub	21.97	19.79	16.20	12.97	9.95	6.69	3.30		8.82	12.28	3.76	4.68	9.21	14.25	13.74	17.77	21.00	141.7	1.79
9-Water	36.03	33.72	29.11	25.16	21.54	17.35	12.79	8.82		3.66	4.66	4.70	4.52	7.17	8	12.74	17.02	128.3	0.89
10-Water	41	39.12	34.15	29.94	26.12	21.59	16.57	12.28	3.66		8.07	7.06	4.03	4.02	6.37	10.21	14.72	117.8	1.66
11-Water	26.88	24.74	20.91	17.54	14.40	10.88	7.15	3.76	4.66	8.07		3.12	6.6	10.68	11.19	15.05	18.73	132.3	0.93
12-Bare Ground	26.76	24.66	21.22	18.15	15.19	11.79	8.16	4.68	4.70	7.06	3.12		4	9.1	8.87	12.78	16.18	114.8	0.78
13-Bare Ground	33.37	31.25	27.36	23.99	20.83	17.07	12.94	9.21	4.52	4.03	6.6	4		5.2	4.40	8.52	12.16	95.0	1.3
14-Water	41.4	39.31	34.71	30.85	27.3	23.08	18.29	14.25	7.17	4.02	10.68	9.1	5.2		3.98	6.30	10.31	90.46	2.41
15-Bare Ground/ Road	39.44	37.31	33.18	29.65	26.35	22.28	17.73	13.74	8	6.37	11.19	8.87	4.40	3.98		4.20	8.08	74.63	2.61
16-Road/ Som Bare Ground	44.43	42.39	37.97	34.29	30.9	26.69	21.84	17.77	12.74	10.21	15.05	12.78	8.52	6.30	4.20		4.10	54.92	3.75
17-Road/ Som Bare Ground	47.49	45.54	41.2	37.64	34.32	30.03	25.09	21.00	17.02	14.72	18.73	16.18	12.16	10.31	8.08	4.10		32.82	4.83
18-Outside/ Roofs	288.0	277.71	254.6	235.5	217.96	193.61	164.8	141.72	128.36	117.82	132.30	114.8	95.0	90.46	74.63	54.92	32.82		35.42
All	8.73	8.10	6.98	6.00	5.05	3.98	2.84	1.79	0.89	1.66	0.93	0.78	1.3	2.41	2.61	3.75	4.83	35.42	

* See Glossary

AREA A 1975 – 10-FOOT PIXELS

Means Summary Report[*] for Area A 1975 – 10-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest (Shadow)/Dark Ground	67.09	27.501	42.668
2-Water, Shadow, Forest	70.849	39.713	56.916
3-Water, Shadow, Forest	75.715	54.723	68.651
4-Bad Class	81.659	71.022	80.160
5-Grass/Shrub	89.265	86.827	91.539
6-Grass/Shrub	99.407	101.775	102.357
7-Grass/Shrub	112.502	117.128	113.137
8-Grass/Shrub	130.357	132.802	124.079
9-River	153.189	170.168	160.973
10-River	165.719	181.674	170.901
11-Shallow Water/Forest	139.633	150.953	142.564
12-Grass/Shrub	163.324	153.038	134.909
13-Gravel/Dirt	184.943	174.670	152.767
14-River	180.678	193.703	183.554
15-Roads/Gravel/Some Bare Ground	206.047	193.544	168.606
16-Roads/Gravel/Some Bare Ground	220.994	211.642	187.069
17-Roads/Gravel/Some Bare Ground	237.481	229.291	204.386
18-Outside/Roofs	254.995	254.994	254.975
All	159.442	153.78	155.493

[*] See Glossary

Standard Deviation Summary Report* for Area A 1975 – 10-Foot Pixels

Class/Region	Band1	Band2	Band3
1-Forest (Shadow)/Dark Ground	4.992	5.906	6.668
2-Water, Shadow, Forest	5.356	5.519	5.879
3-Water, Shadow, Forest	5.682	5.909	6.541
4-Bad Class	6.042	5.954	6.820
5-Grass/Shrub	6.625	5.682	7.093
6-Grass/Shrub	7.670	5.831	7.525
7-Grass/Shrub	9.091	6.587	8.121
8-Grass/Shrub	10.589	6.599	8.130
9-River	6.421	4.722	6.415
10-River	5.924	4.138	5.952
11-Shallow Water/Forest	7.947	6.626	7.780
12-Grass/Shrub	8.076	7.892	8.763
13-Gravel/Dirt	8.825	6.414	8.015
14-River	6.727	4.974	7.497
15-Roads/Gravel/Some Bare Ground	7.884	6.138	8.170
16-Roads/Gravel/Some Bare Ground	8.366	5.592	8.236
17-Roads/Gravel/Some Bare Ground	7.526	6.639	8.836
18-Outside/Roofs	0.222	0.214	0.715
All	78.426	86.722	81.436

* See Glossary

Area Summary Report for Area A 1975 – 10-Foot Pixels

Class/Region	Hectares	Sq. Km.	Acres	Sq. Miles
1-Forest (Shadow)/Dark Ground	37.027	0.370	91.497	0.143
2-Water, Shadow, Forest	54.647	0.546	135.037	0.211
3-Water, Shadow, Forest	50.121	0.501	123.852	0.194
4-Bad Class	49.802	0.498	123.062	0.192
5-Grass/Shrub	47.645	0.476	117.734	0.184
6-Grass/Shrub	41.151	0.412	101.687	0.159
7-Grass/Shrub	33.220	0.332	82.089	0.128
7-Grass/Shrub	22.690	0.227	56.067	0.088
9-River	19.814	0.198	48.962	0.077
10-River	25.062	0.251	61.928	0.097
11-Shallow Water/Forest	9.945	0.099	24.575	0.038
12-Grass/Shrub	8.237	0.082	20.354	0.032
13-Gravel/Dirt	6.152	0.062	15.202	0.024
14-River	14.983	0.150	37.025	0.058
15-Roads/Gravel/Some Bare Ground	5.733	0.057	14.167	0.022
16-Roads/Gravel/Some Bare Ground	6.879	0.069	17.000	0.027
17-Roads/Gravel/Some Bare Ground	4.952	0.050	12.236	0.019
18-Outside/Roofs	240.119	2.401	593.347	0.927
All	678.181	6.782	1675.822	2.618

Distance Between Class/Region Means* for Area A 1975 - 10-Foot Pixels

	1-Fore (Shadow)/ Da	2-Wate Shadov	3-Wate Shadov	4-Ba Cla	5-Gras Shru	6-Gras Shru	7-Gras Shru	8-Gras Shru	9-Riv	10-Riv	11- Wate Fore	12-Gras Shru	13-Grave Di	14-Riv	15-Road Gravel/ Son	16-Road Gravel/ Son	17-Road Gravel/ Son	18-Outsid Roo	A
1-Forest (Shadow)/ Dark		3.20	6.27	9.58	13.04	16.07	18.53	21.96	35.89	41.42	26.73	26.71	33.37	41.49	39.27	44.42	47.4	286	8.73
2-Water, Shadow Forest	3.20		3.35	6.84	10.44	13.64	16.3	19.86	33.72	39.20	24.69	24.7	31.38	39.52	37.29	42.55	45.69	277.63	8.13
3-Water, Shadow Forest	6.27	3.35		3.39	6.84	10.01	12.78	16.2	29.07	34.18	20.84	21.23	27.43	34.85	33.12	38.07	41.32	254.18	7.00
4-Bad Class	9.58	6.84	3.39		3.39	6.60	9.54	1	25.11	29.95	17.47	18.16	24.03	30.95	29.59	34.37	37.73	234.98	6.02
5-Grass/ Shrub	13.04	10.44	6.84	3.39		3.31	6.44	9.9	21.46	26.0	14.30	15.18	20.83	27.40	26.2	30.97	34.37	217.23	5.06
6-Grass/ Shrub	16.07	13.64	10.01	6.60	3.31		3.2	6.67	17.31	21.59	10.80	11.79	17.09	23.15	22.24	26.76	30.11	193.27	3.99
7-Grass/ Shrub	18.53	16.3	12.78	9.54	6.44	3.2		3.28	12.75	16.56	7.07	8.16	12.95	18.34	17.68	21.88	25.13	164.3	2.85
8-Grass/ Shrub	21.96	19.86	16.2	1	9.9	6.67	3.28		8.86	12.35	3.73	4.71	9.2	14.37	13.76	17.90	21.12	141.87	1.81
9-River	35.89	33.72	29.07	25.11	21.46	17.31	12.75	8.86		3.67	4.71	4.68	4.44	7.18	8.66	12.79	17.08	127.72	0.88
10-River	41.42	39.20	34.18	29.95	26.0	21.59	16.56	12.35	3.67		8.13	7.07	3.97	4.02	6.36	10.28	14.81	117.42	1.65
11-Shallow Water/ Forest	26.73	24.69	20.84	17.47	14.30	10.80	7.07	3.73	4.71	8.13		3.11	6.64	10.7	11.21	15.16	18.84	132.08	0.95
12-Grass/ Shrub	26.71	24.7	21.23	18.16	15.18	11.79	8.16	4.71	4.68	7.07	3.11		4.5	9.14	8.85	12.83	16.24	114.63	0.78
13-Gravel/ Dirt	33.37	31.38	27.43	24.03	20.83	17.09	12.95	9.2	4.44	3.97	6.64	4.5		5.23	4.39	8.57	12.21	95.01	1.31
14-River	41.49	39.52	34.85	30.95	27.40	23.15	18.34	14.37	7.18	4.02	10.7	9.14	5.23		3.97	6.37	10.42	90.42	2.41
15-Roads/ Grave Some Bare	39.27	37.29	33.12	29.59	26.2	22.24	17.68	13.76	8.66	6.36	11.21	8.85	4.39	3.97		4.24	8.10	74.29	2.59
16-Roads/ Grave Some Bare	44.42	42.55	38.07	34.37	30.97	26.76	21.88	17.90	12.79	10.28	15.16	12.83	8.57	6.37	4.24		4.10	54.55	3.76
17-Roads/ Grave Some Bare	47.4	45.69	41.32	37.73	34.37	30.11	25.13	21.12	17.08	14.81	18.84	16.24	12.21	10.42	8.10	4.10		32.45	4.85
18-Outside/ Roo	286	277.63	254.18	234.9	217.2	193.2	164.3	141.8	127.7	117.42	132.08	114.63	95.01	90.42	74.29	54.55	32.45		35
All	8.73	8.13	7.00	6.02	5.06	3.99	2.85	1.81	0.88	1.65	0.95	0.78	1.31	2.41	2.59	3.76	4.85	35	

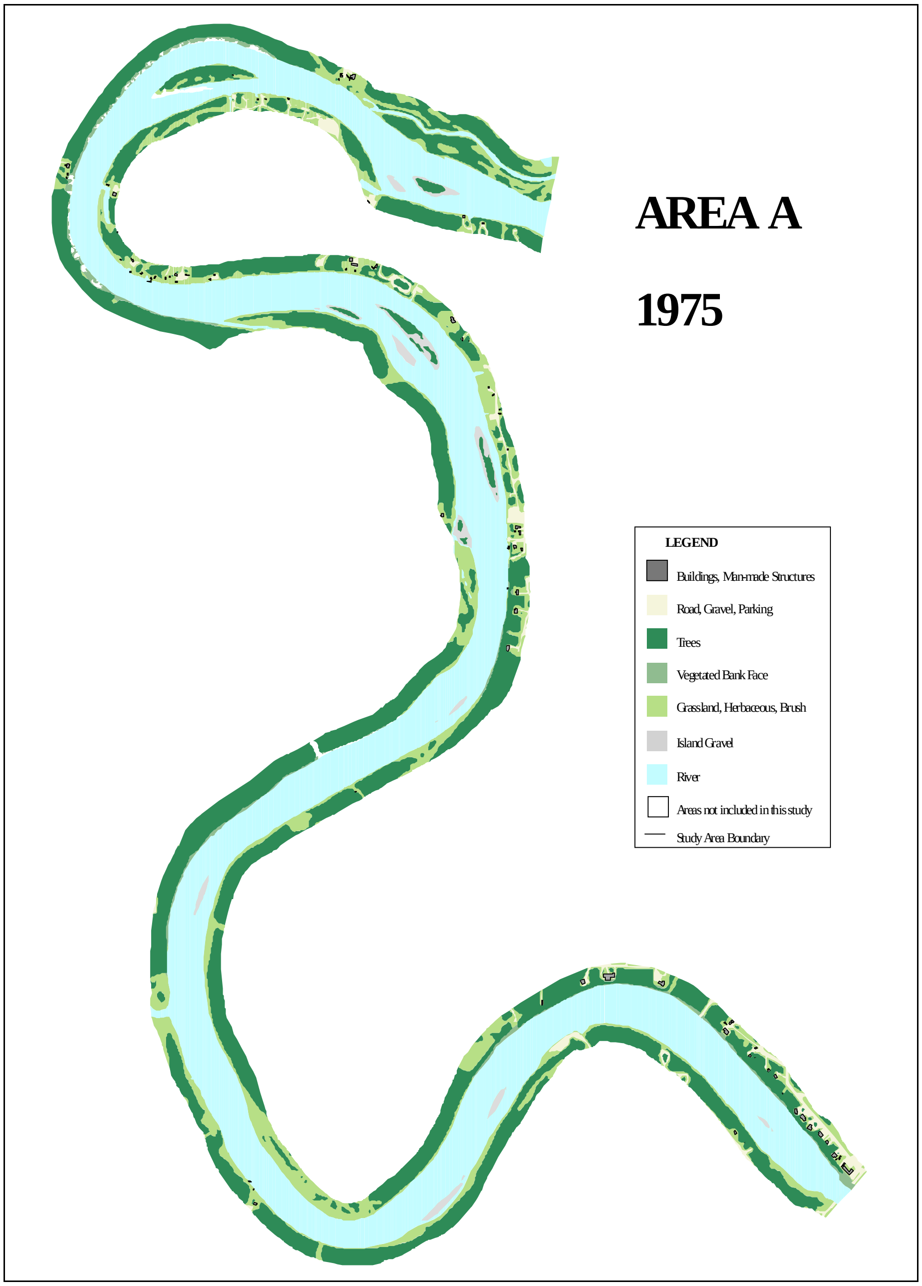
* See Glossary

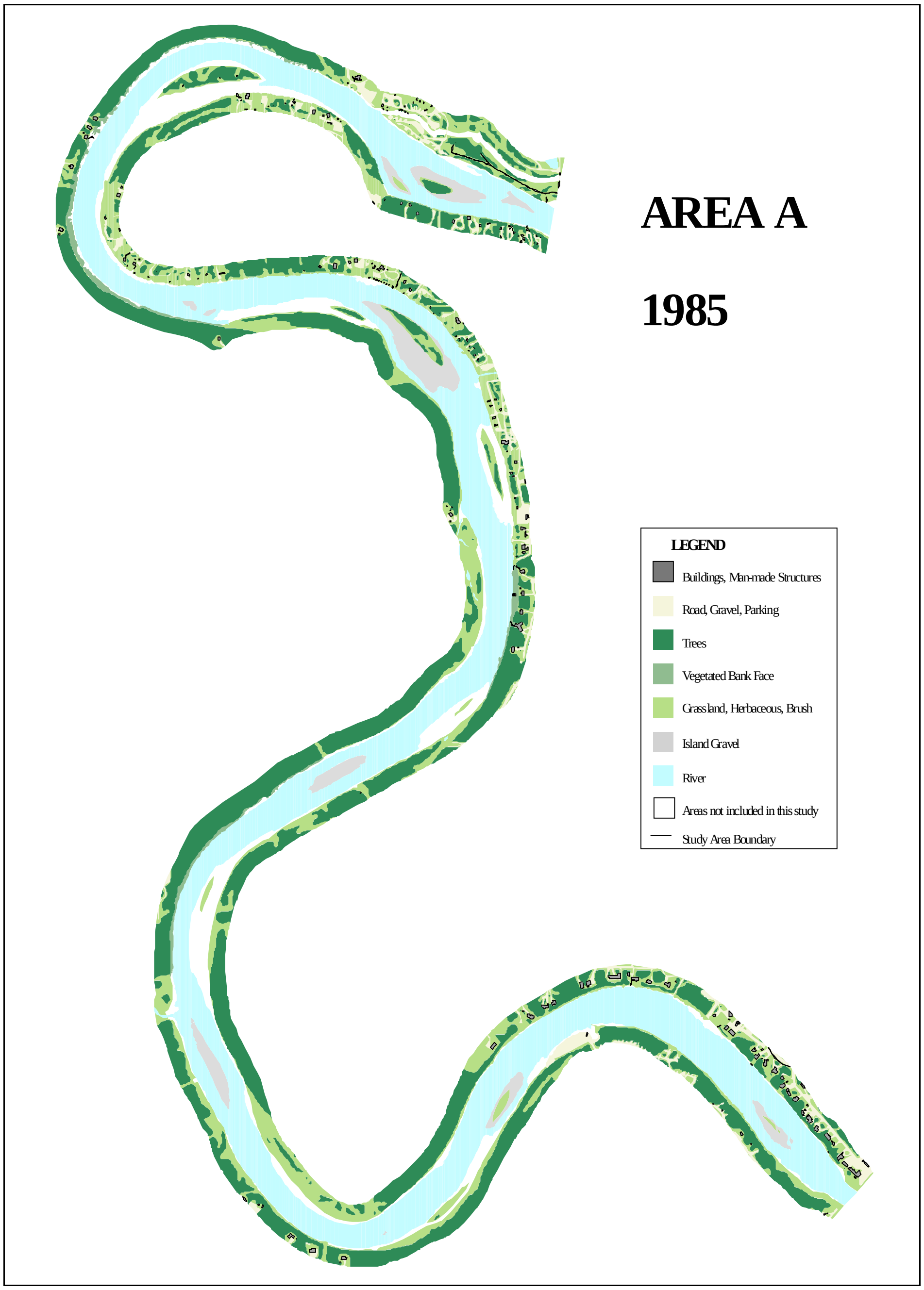
RANDOM POINTS RESAMPLING COMPARISON

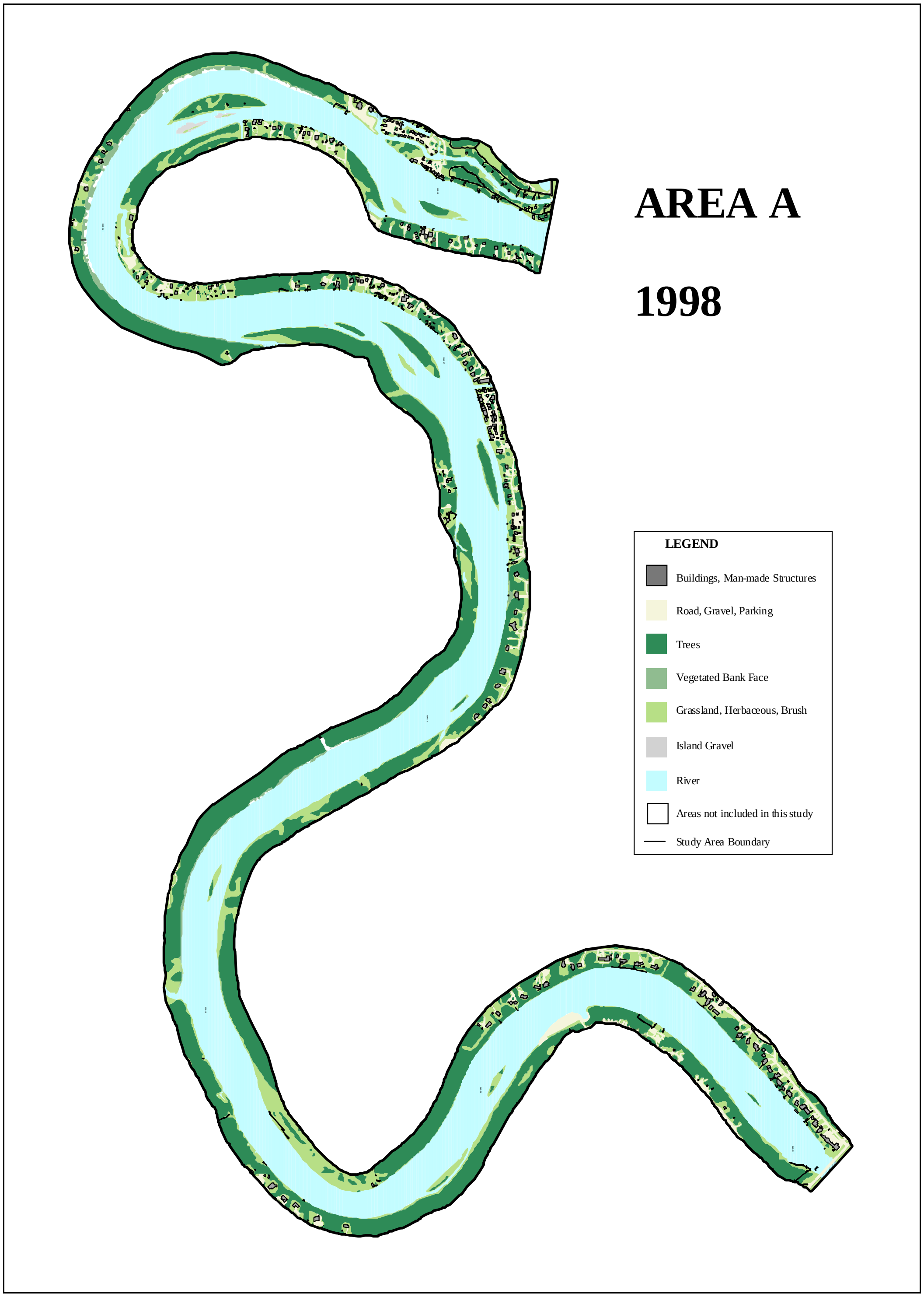
IMAGE	TEN_FOOT	FIVE_FOOT	THREE_FOOT
Grass/Shrub	Grass / Shrub	Grass / Shrub	Grass / Shrub
Road	Roads / Gravel	Road / Bare Ground	Roads / Gravel
Water	Shallow Water / Forest	River	Water
Road	Roads / Gravel	Road / Bare Ground	Roads / Gravel
Grass/Shrub	Grass / Shrub	Grass / Shrub / Forest Shadow	Grass / Shrub
Water	Shallow Water / Forest	River	Water
Forest	Water, Shadow, Forest	Bare Ground / Forest Shadow	Forest Shadow / Dark Ground
Grass	Grass / Shrub	Dark Bare Ground / Grass / Shrub	Grass / Shrubs
Forest	Forest (Shadow) / Dark Ground	Grass / Shrub	Forest Shadow / Dark Ground
Grass/Shrub	Grass / Shrub	Grass / Shrub / Forest Shadow	Grass / Shrub
Forest	Forest (Shadow) / Dark Ground	Bare Ground / Forest Shadow	Forest Shadow / Dark Water
Forest	Water, Shadow, Forest	Bare Ground / Forest Shadow	Grass / Shrub
Grass/Shrub	Grass / Shrub	Dark Bare Ground / Grass / Shrub	Bare Ground
Road	Roads / Gravel	Road / Bare Ground	Roads / Gravel
Grass/Shrub	Grass / Shrub	Bare Ground / Forest Shadow	Grass / Shrub
Forest	Forest (Shadow) / Dark Ground	Forest (Shadow)	Forest Shadow / Dark Ground
Forest	Forest (Shadow) / Dark Ground	Bare Ground / Forest Shadow	Forest Shadow / Dark Ground
Forest	Water, Shadow, Forest	Bare Ground / Forest Shadow	Forest Shadow / Dark Water
Grass	Grass / Shrub	Dark Bare Ground / Grass / Shrub	Grass / Shrub
Bare Ground	Roads, Gravel	Road / Bare Ground	Roads / Gravel
Forest	Water, Shadow, Forest	Bare Ground / Forest Shadow	Forest Shadow / Dark Ground
Water	River	Bare Ground / Forest Shadow	Water
Grass/Shrub	Forest (Shadow) / Dark Ground	Bare Ground / Forest Shadow	Forest Shadow / Dark Ground
Forest	Grass / Shrub	Bare Ground / Forest Shadow	Forest Shadow / Dark Ground
Bare Ground	Grass / Shrub	Dark Bare Ground / Grass / Shrub	Roads / Gravel
Forest	Grass / Shrub	Bare Ground / Forest Shadow	Grass / Shrub

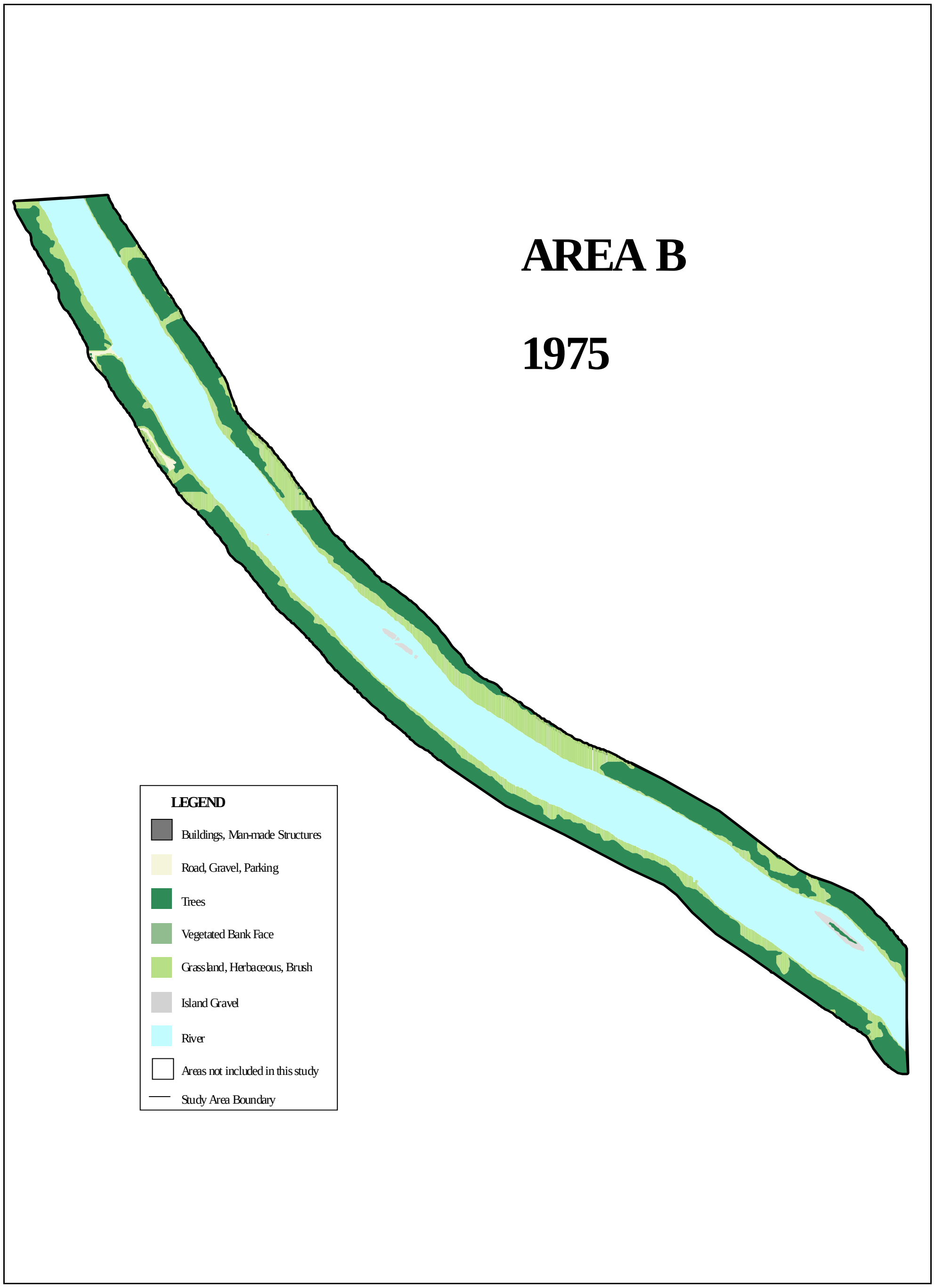
APPENDIX B:

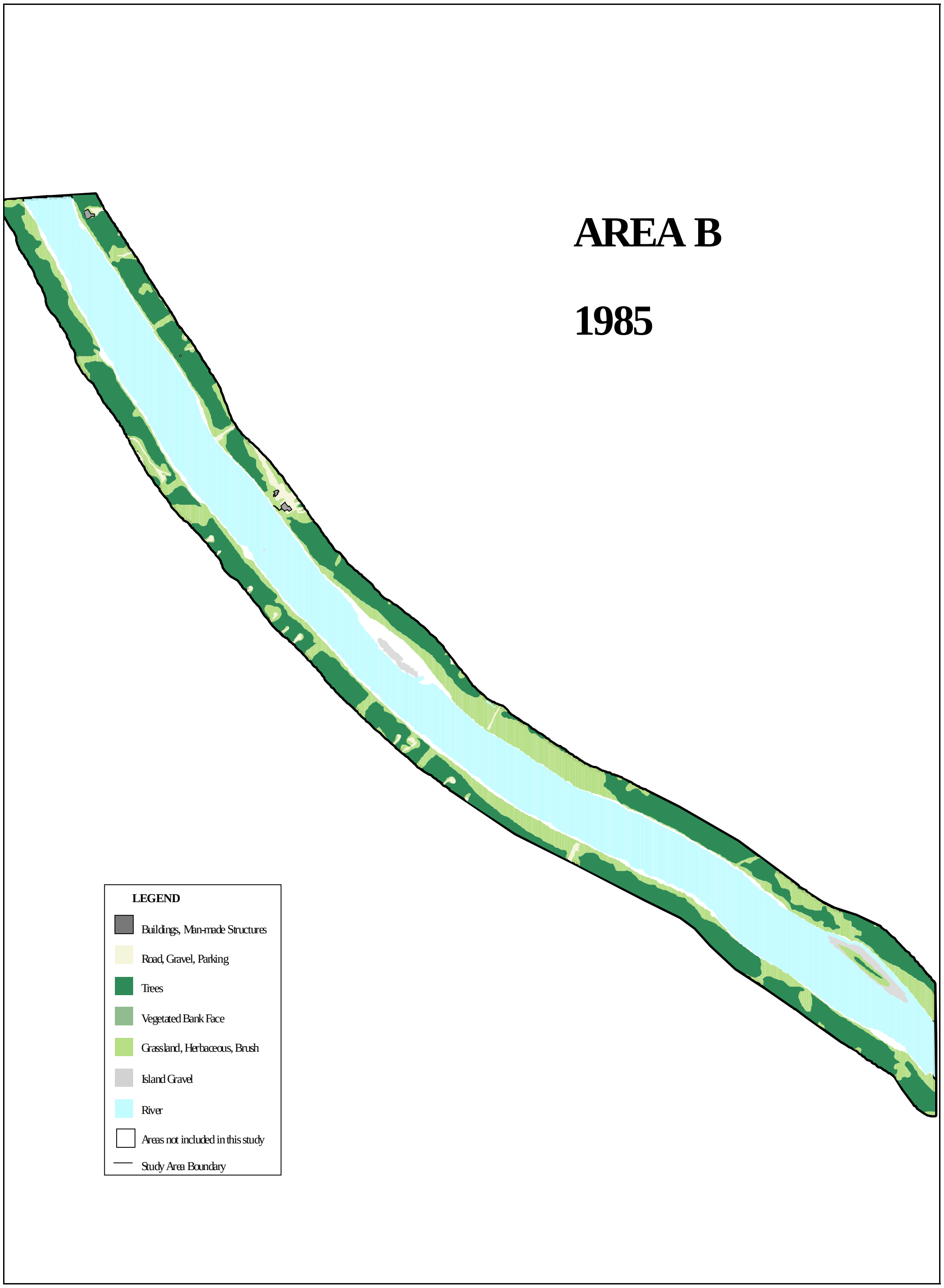
The following maps contain the photogrammetrically derived landcover data for both of the study areas for the three years of interest. Landcover types include: Buildings, man-made structures; Road, Gravel, Parking; Trees; Vegetated Bank Face; Grassland, Herbaceous, Brush; Island Gravel; and River.



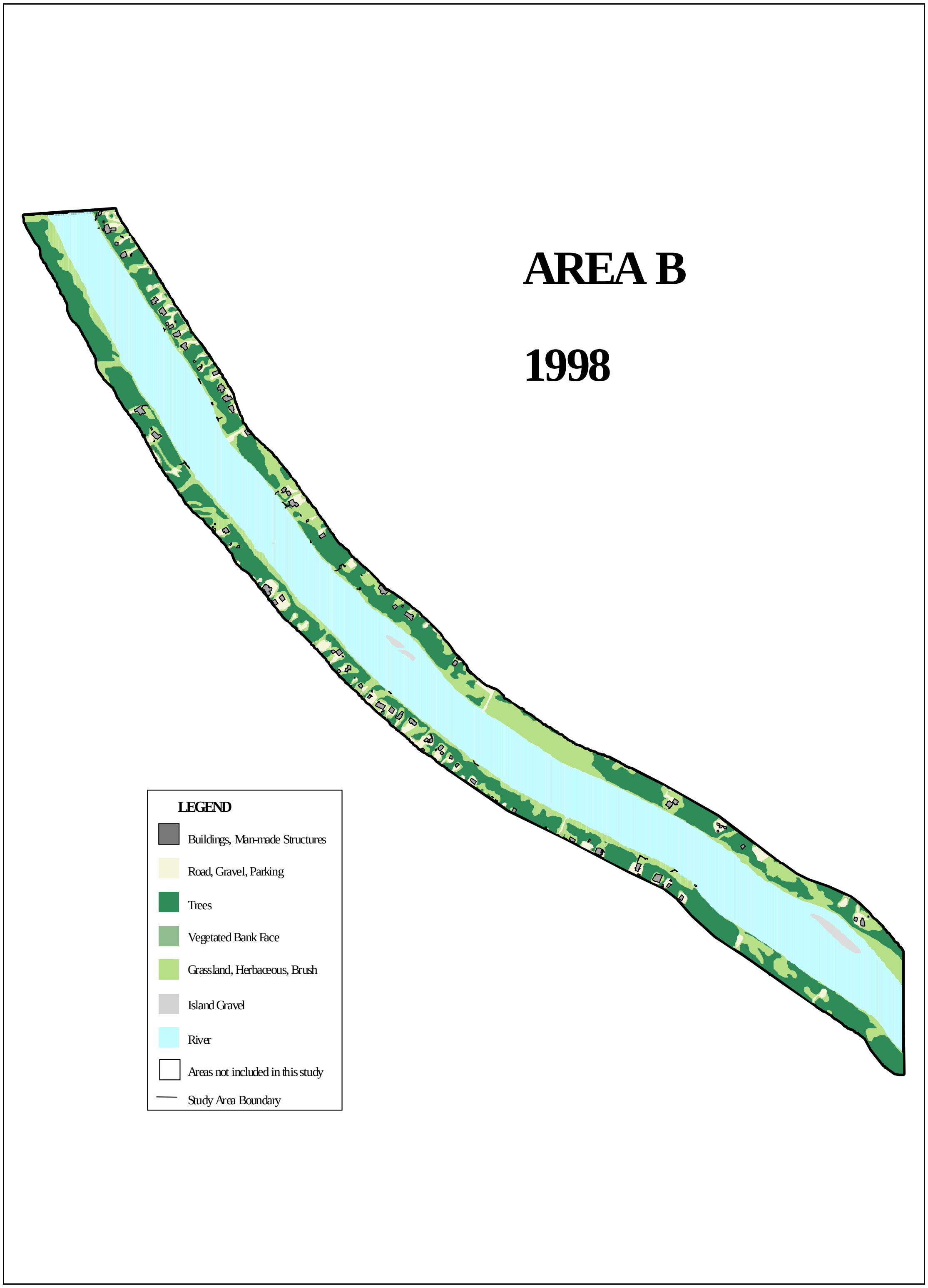

AREA A
1985
LEGEND
Buildings, Man-made Structures
Road, Gravel, Parking
Trees
Vegetated Bank Face
Grassland, Herbaceous, Brush
Island Gravel
River
Areas not included in this study
Study Area Boundary


AREA A
1998
LEGEND
Buildings, Man-made Structures
Road, Gravel, Parking
Trees
Vegetated Bank Face
Grassland, Herbaceous, Brush
Island Gravel
River
Areas not included in this study
Study Area Boundary


AREA B
1975
LEGEND
Buildings, Man-made Structures
Road, Gravel, Parking
Trees
Vegetated Bank Face
Grassland, Herbaceous, Brush
Island Gravel
River
Areas not included in this study
Study Area Boundary



AREA B
1985
LEGEND
Buildings, Man-made Structures
Road, Gravel, Parking
Trees
Vegetated Bank Face
Grassland, Herbaceous, Brush
Island Gravel
River
Areas not included in this study
Study Area Boundary


AREA B
1998
LEGEND
Buildings, Man-made Structures
Road, Gravel, Parking
Trees
Vegetated Bank Face
Grassland, Herbaceous, Brush
Island Gravel
River
Areas not included in this study
Study Area Boundary

GLOSSARY

BAND

A division of the electromagnetic spectrum. For this project, the visible spectrum is divided into the red, green and blue bands.

IMAGE CLASSIFICATION

Process of assigning individual pixels of an image to categories, generally on the basis of spectral reflectance characteristics. (Sabins 1997)

Note: Spectral reflectance characteristics are simply the measurements by the sensor (in this case a camera and film) of the amount of energy (light) reflected or emitted in band. So, generally speaking, classification is the process of grouping pixels with similar values for all measurements made.

PHOTOGRAMMETRICALLY DERIVED DATA

Photogrammetry is defined by Miriam-Webster as "The science of making reliable measurements by the use of photographs esp. aerial photographs (as in surveying)". The features derived for this project using photogrammetry, therefore are reliable depictions of features visible in the aerial photography from which they were made.

PIXEL

Each pixel, or cell, in each band consists of a measurement between 0 and 255 proportional to the brightness in each band of the surface measured.

SUMMARY REPORTS

Area: A report generated after image classification. Lists the area of each class in the study area.

Means: A report generated after image classification. Lists the average values (means) of pixel values for each band in each class.

Distance Between Class/Region Means: A report generated after image classification. Lists a measure of the differences between the means of the classes. The larger the difference between the means, the more distinct the classes are.

Standard Deviation: A report generated after image classification. Lists the standard deviation of the pixel values for each band in each class.

SUPERVISED CLASSIFICATION

Digital-information extraction technique in which the operator provides training sites to the computer for use in assigning pixels to categories.

MAXIMUM LIKELIHOOD CLASSIFICATION (WITH EQUAL PRIOR PROBABILITIES)

This classifier takes into account the directional spread of class data in multispectral space. This is the recommended classifier if good quality training regions are available, but no knowledge of prior probabilities exists. (Earth Resource Mapping Ltd 2001)

MINIMUM DISTANCE CLASSIFICATION

This formula measures the [Euclidian] distance from the training region mean. The greater the distance, the less likely the cell belongs to the class. This classifier is not as flexible as Maximum Likelihood, but is a better choice if the training region is small or of poor quality. (Earth Resource Mapping Ltd 2001)

PARALLELEPIPED CLASSIFICATION

This classification formula checks if the band value for each cell is within the minimum and maximum values of the band for the specified training region. If this is the case, it is considered part of the class. This is a very simple classifier, not usually considered as good as the others. (Earth Resource Mapping Ltd 2001)

TRAINING SITES

Selected areas, usually from the same image, which represent the different classes in the image. Statistics for each training area are calculated and the classification procedure is performed based on these statistics. The values for each band for each pixel are compared to each training site's statistics based on the formula (supervised classification technique) used.

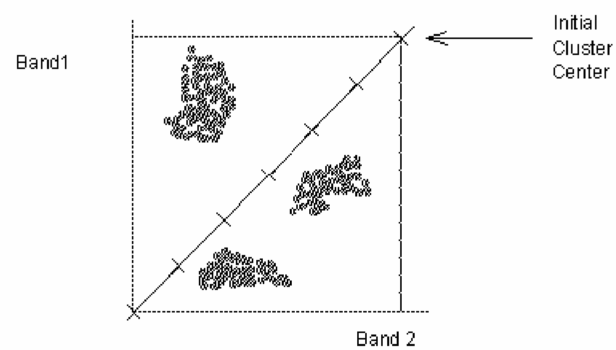
UNSUPERVISED CLASSIFICATION

Unsupervised Classification is carried out using little or no [prior] information about possible classes, and automatically identifies [pixel] clusters of similar data. The algorithm used for unsupervised classification is iterative: it groups data automatically, recalculating class means, and merging and splitting classes as required. Generally, one specifies the number of classes to be found. Several other parameters control processing and completing the classification. These parameters are described below.

The Unsupervised ISOCLASS algorithm

The ISOCLASS algorithm is used for unsupervised classification. In the simple two band example illustration, the data falls into three clusters:

Initial cluster centers are seeded, spaced evenly along the diagonal. In this example six starting classes are specified.



The distance of every data point from each center is calculated. Each point is allocated to the cluster with the closest center. The center of each cluster (the average coordinate in each dimension) is recalculated and any merging or splitting of classes is carried out.

The whole process is repeated until one of the following processing limits has been reached.

Parameters:

Autogenerate Ordinarily, the process seeds the cluster centers with one cluster. Autogenerate speeds the processing by beginning with more centers.

Maximum iterations The maximum number of times to classify the data points and recalculate cluster centers. If the class means become stable before the maximum number of iterations is reached, processing will stop (see Desired percent unchanged below).

Desired percent unchanged The percentage of cells that have not changed class between iterations. This is reported for each iteration in the Processing Status dialog box.

Maximum number of classes The maximum number of classes in the classified Output Dataset. (Earth Resource Mapping Ltd 2001)

VEGETATION INDEXES

Vegetation indexes are designed to highlight the differences between vegetated and non-vegetated areas, as well as differences in vegetation vigor. Generally, these indexes depend on the difference between reflectivity in the red band and the near infrared (NIR) band. In an area with vigorous vegetation, the reflectivity of the surface in the red band is low (chlorophyll absorbs energy in the red wavelength) and high in the near infrared wavelength (chlorophyll reflects energy in the red wavelength). There are several different formulas that highlight different aspects of the differences in value between the two bands. One of the most popular is the Normalized Difference Vegetation Index:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

REFERENCES

Earth Resource Mapping Ltd, 1997, ER Mapper User Guide.
Merriam Webster, Inc., 1990. *Webster's Ninth New Collegiate Dictionary,* Merriam-Webster, Inc., Springfield, MA
Sabins, F.F., 1997, *Remote Sensing: Principles and Interpretation*, W. H. Freeman and Company, New York.

APPENDIX C: LANDCOVER CLASS TRANSITION SUMMARY

Appendix C1.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for islands in study area A, Kenai River.

	Landcover Class Assignment								Total Area		
Count of Polygons[a]	1975	1985	1998	Min Area	Max Are	Ave Are	SD Are	Variance Are	Sq. Fee	Acre	Transitio Code
1	Cleared Area	Tree	Tree	10.	10.	10.	0.	0.	10.	0.0	8
9	Cleared Area	Groundcover	Tree	0.	672.	165.	258.	66,738.	1,492.	0.0	8
1	Cleared Area	Substrate	Groundcover	1,502.	1,502.	1,502.	0.	0.	1,502.	0.0	8
2	Cleared Area	Cleared Area	Tree	113.	1,544.	828.	1,012.	1,024,596.	1,657.	0.0	8
4	Cleared Area	Cleared Area	Groundcover	1.	4,192.	1,193.	2,004.	4,016,770.	4,775.	0.1	8
5	Cleared Area	Groundcover	Groundcover	166.	10,424.	2,840.	4,302.	18,514,474.	14,203.	0.3	8
1	Cleared Area	Cleared Area	Structure	30.	30.	30.	0.	0.	30.	0.0	9
2	Cleared Area	Cleared Area	Cleared Area	1,086.	2,532.	1,809.	1,022.	1,044,978.	3,618.	0.0	9
2	Cleared Area	Substrate	River	75.	539.	307.	328.	107,701.	614.	0.0	14
5	Cleared Area	Groundcover	Cleared Area	0.	394.	190.	143.	20,689.	953.	0.0	15
322	Groundcover	Groundcover	Tree	0.	36,115.	764.	3,276.	10,733,820.	246,238.	5.6	1
420	Groundcover	Tree	Tree	0.	21,769.	75.	1,076.	1,158,927.	31,751.	0.7	1
8	Groundcover	Cleared Area	Cleared Area	17.	8,757.	2,693.	2,710.	7,344,625.	21,547.	0.4	2
3	Groundcover	Cleared Area	Structure	3.	1,192.	410.	677.	459,046.	1,230.	0.0	2
3	Groundcover	Structure	Structure	170.	3,885.	1,783.	1,905.	3,628,835.	5,351.	0.1	2
10	Groundcover	Cleared Area	Groundcover	14.	26,739.	3,381.	8,332.	69,436,047.	33,817.	0.7	3
3	Groundcover	Cleared Area	Tree	61.	153.	97.	49.	2,413.	293.	0.0	3
3	Groundcover	Structure	Groundcover	6.	158.	60.	85.	7,229.	181.	0.0	3
3	Groundcover	Cleared Area	River	3.	651.	349.	326.	106,500.	1,048.	0.0	4
27	Groundcover	Groundcover	Cleared Area	0.	8,006.	735.	1,647.	2,712,858.	19,852.	0.4	5
22	Groundcover	Groundcover	Structure	2.	801.	161.	221.	48,971.	3,541.	0.0	5
1	Groundcover	River	Structure	1.	1.	1.	0.	0.	1.	0.0	5
1	Groundcover	Substrate	Cleared Area	49.	49.	49.	0.	0.	49.	0.0	5
13	Groundcover	Substrate	Structure	1.	375.	97.	118.	14,138.	1,273.	0.0	5
16	Groundcover	Tree	Cleared Area	0.	941.	76.	239.	57,357.	1,222.	0.0	5
9	Groundcover	Tree	Structure	0.	372.	65.	122.	15,114.	592.	0.0	5
64	Groundcover	Groundcover	Groundcover	0.	322,783.	14,786.	43,661.	1,906,325,827.	946,309.	21.7	6

-continued-

Appendix C1.–Page 2 of 3.

Count of Polygons[a]	Landcover Class Assignment 1975	1985	1998	Min Area	Max Are	Ave Are	SD Are	Variance Are	Total Area Sq. Fee	Acre	Transitio Code
10	Groundcover	River	River	1.	1,586.	340.	558.	312,361.	3,400.	0.0	7
50	Groundcover	Substrate	Groundcover	0.	15,917.	1,679.	3,026.	9,157,521.	83,965.	1.9	7
64	Groundcover	Substrate	River	0.	11,040.	756.	1,784.	3,184,651.	48,398.	1.1	7
6	Groundcover	Substrate	Tree	7.	617.	160.	238.	56,843.	964.	0.0	7
6	Groundcover	Tree	River	0.	0.	0.	0.	0.	0.	0.0	7
306	Groundcover	Tree	Groundcover	0.	3,220.	20.	190.	36,295.	6,227.	0.1	13
22	Tree	Cleared Area	Cleared Area	17.	3,811.	1,191.	1,043.	1,087,816.	26,221.	0.6	2
6	Tree	Cleared Area	Structure	90.	2,244.	578.	831.	690,487.	3,473.	0.0	2
1	Tree	Structure	Cleared Area	82.	82.	82.	0.	0.	82.	0.0	2
4	Tree	Structure	Structure	33.	4,227.	1,162.	2,047.	4,191,930.	4,649.	0.1	2
19	Tree	Cleared Area	Groundcover	0.	2,418.	319.	591.	349,511.	6,068.	0.1	3
7	Tree	Cleared Area	Tree	0.	251.	102.	111.	12,311.	715.	0.0	3
2	Tree	Structure	Groundcover	30.	159.	94.	90.	8,238.	189.	0.0	3
1	Tree	Structure	Tree	23.	23.	23.	0.	0.	23.	0.0	3
91	Tree	Tree	Cleared Area	0.	10,484.	1,890.	2,453.	6,019,409.	172,020.	3.9	5
101	Tree	Tree	Structure	5.	5,334.	1,065.	1,224.	1,498,087.	107,588.	2.4	5
55	Tree	Tree	Tree	1.	222,509.	36,805.	50,626.	2,563,029,364.	2,024,322.	46.4	6
1	Tree	Substrate	Groundcover	14.	14.	14.	0.	0.	14.	0.0	7
1	Tree	Tree	River	938.	938.	938.	0.	0.	938.	0.0	7
45	Tree	Groundcover	Cleared Area	0.	8,854.	1,050.	1,949.	3,799,638.	47,248.	1.0	10
34	Tree	Groundcover	Structure	0.	1,656.	211.	349.	122,321.	7,176.	0.1	10
440	Tree	Groundcover	Groundcover	0.	38,639.	320.	2,045.	4,182,512.	141,051.	3.2	11
479	Tree	Groundcover	Tree	0.	45,740.	215.	2,167.	4,696,744.	103,378.	2.3	11
1	Tree	Pond	Cleared Area	1,578.	1,578.	1,578.	0.	0.	1,578.	0.0	11
5	Tree	Groundcover	River	0.	1.	0.	0.	0.	2.	0.0	12
471	Tree	Tree	Groundcover	0.	25,179.	881.	2,834.	8,035,445.	415,011.	9.5	13

-continued-

[a] Total number of polygons assessed to have this landcover class transition.

[b] Area of the smallest polygon assessed for this landcover class transition.

[c] Area of the largest polygon assessed for this landcover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:

1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.

2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)

3 = Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

4 = Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.

6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.

7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).

8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998.

9 = Impact, no change: originally impacted and remained impacted.

10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.

11 = Natural-impact (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.

12 = Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.

13 = Natural-natural-impact (clearing): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.

14 = Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.

16 = Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.

15 = Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.

17 = Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.

18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

19 = River, unchanged: classified as a river for each year assessed.

Appendix C2.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for the mainland in study area A, Kenai River.

	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
209	Cleared Area	Cleared Area	Groundcover	0.0	11,968.2	319.3	939.4	882,473.6	66,740.0	1.53	8
20	Cleared Area	Cleared Area	Tree	0.3	403.9	97.3	127.7	16,295.4	1,946.7	0.04	8
250	Cleared Area	Groundcover	Groundcover	0.0	8,316.6	407.1	904.9	818,793.4	101,784.1	2.34	8
51	Cleared Area	Groundcover	Tree	0.0	1,210.3	203.8	280.3	78,588.5	10,391.7	0.24	8
1	Cleared Area	Groundcover	VBF	0.1	0.1	0.1	0.0	0.0	0.1	0.00	8
2	Cleared Area	Harbor	Groundcover	9.2	190.2	99.7	128.0	16,377.3	199.4	0.00	8
29	Cleared Area	Structure	Groundcover	0.2	258.9	71.0	65.1	4,234.4	2,060.1	0.05	8
8	Cleared Area	Structure	Tree	12.4	125.9	60.1	36.8	1,356.3	480.9	0.01	8
2	Cleared Area	Substrate	Groundcover	31.3	255.0	143.1	158.2	25,014.6	286.3	0.01	8
2	Cleared Area	Substrate	VBF	0.1	1.2	0.6	0.8	0.6	1.2	0.00	8
19	Cleared Area	Tree	Groundcover	0.1	2,783.0	238.4	634.4	402,438.1	4,528.8	0.10	8
24	Cleared Area	Tree	Tree	0.0	2,762.2	286.1	623.1	388,251.2	6,867.1	0.16	8
73	Cleared Area	Cleared Area	Cleared Area	0.1	77,180.4	4,582.6	10,170.8	103,445,781.3	334,531.9	7.68	9
2	Cleared Area	Cleared Area	Harbor	65.4	772.8	419.1	500.2	250,169.1	838.2	0.02	9
76	Cleared Area	Cleared Area	Structure	0.1	1,489.2	201.7	270.8	73,357.6	15,329.9	0.35	9
1	Cleared Area	Harbor	Cleared Area	2.1	2.1	2.1	0.0	0.0	2.1	0.00	9
2	Cleared Area	Harbor	Harbor	490.0	562.5	526.2	51.2	2,623.5	1,052.5	0.02	9
22	Cleared Area	Structure	Cleared Area	0.0	616.0	129.3	174.6	30,473.3	2,844.8	0.07	9
43	Cleared Area	Structure	Structure	0.0	1,513.7	234.4	281.9	79,441.8	10,080.4	0.23	9
1	Cleared Area	Substrate	Cleared Area	72.3	72.3	72.3	0.0	0.0	72.3	0.00	9
1	Cleared Area	Substrate	Structure	6.4	6.4	6.4	0.0	0.0	6.4	0.00	9
1	Cleared Area	Harbor	River	174.1	174.1	174.1	0.0	0.0	174.1	0.00	14
2	Cleared Area	Cleared Area	River	3.6	272.5	138.1	190.2	36,161.3	276.1	0.01	14
2	Cleared Area	Substrate	River	168.6	317.5	243.0	105.3	11,086.8	486.1	0.01	14
1	Cleared Area	VBF	River	57.7	57.7	57.7	0.0	0.0	57.7	0.00	14
1	Cleared Area	VBF	VBF	373.2	373.2	373.2	0.0	0.0	373.2	0.01	14
193	Cleared Area	Groundcover	Cleared Area	0.0	3,530.3	226.5	504.8	254,777.6	43,704.9	1.00	15
3	Cleared Area	Groundcover	Harbor	8.2	26.5	15.2	9.9	98.3	45.6	0.00	15
75	Cleared Area	Groundcover	Structure	0.0	1,234.4	160.9	263.3	69,336.7	12,069.0	0.28	15
16	Cleared Area	Tree	Cleared Area	0.0	850.4	140.6	273.5	74,776.4	2,249.5	0.05	15
6	Cleared Area	Tree	Structure	0.2	188.2	49.0	69.7	4,856.4	294.3	0.01	15
5	Cleared Area	Groundcover	River	0.0	1,504.6	367.6	638.5	407,650.8	1,837.9	0.04	16
7	Backwater	Groundcover	Groundcover	0.2	1,365.2	372.3	496.4	246,416.4	2,606.0	0.06	1
1	Backwater	Substrate	Groundcover	102.4	102.4	102.4	0.0	0.0	102.4	0.00	1

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	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
3	Backwater	Backwater	Backwater	372.2	7,090.7	2,675.1	3,825.3	14,632,701.1	8,025.2	0.18	7
5	Backwater	Groundcover	Backwater	5.7	21,571.1	5,425.6	9,123.7	83,241,973.6	27,127.8	0.62	7
1	Backwater	Groundcover	VBF	18.2	18.2	18.2	0.0	0.0	18.2	0.00	7
1	Backwater	River	River	544.9	544.9	544.9	0.0	0.0	544.9	0.01	7
2	Backwater	Substrate	Backwater	562.9	2,171.2	1,367.0	1,137.3	1,293,353.9	2,734.0	0.06	7
2	Backwater	Substrate	River	175.8	954.6	565.2	550.7	303,216.1	1,130.4	0.03	7
5	Groundcover	Groundcover	Backwater	0.1	550.4	196.7	217.0	47,097.0	983.4	0.02	1
1	Groundcover	Groundcover	Tree	26,632.4	26,632.4	26,632.4	0.0	0.0	26,632.4	0.61	1
2	Groundcover	Tree	Tree	176.0	728.3	452.2	390.5	152,503.4	904.3	0.02	1
16	Groundcover	Groundcover	Backwater	1.5	8,556.3	1,151.8	2,202.8	4,852,286.8	18,428.4	0.42	1
421	Groundcover	Groundcover	Tree	0.0	66,532.6	1,538.6	6,156.2	37,899,245.2	647,758.9	14.87	1
1	Groundcover	Pond	Backwater	1,434.0	1,434.0	1,434.0	0.0	0.0	1,434.0	0.03	1
5	Groundcover	Pond	Groundcover	8.3	1,409.4	375.4	595.8	354,922.8	1,876.9	0.04	1
4	Groundcover	Pond	Pond	16.2	984.1	361.1	429.8	184,721.6	1,444.3	0.03	1
4	Groundcover	Pond	Tree	5.7	265.2	86.7	120.4	14,505.0	346.9	0.01	1
22	Groundcover	Substrate	Tree	0.6	2,855.4	281.6	621.2	385,912.2	6,195.7	0.14	1
353	Groundcover	Tree	Groundcover	0.0	2,895.5	147.0	330.5	109,237.3	51,884.0	1.19	1
412	Groundcover	Tree	Tree	0.0	44,509.4	793.3	2,982.2	8,893,684.5	326,846.0	7.50	1
1	Groundcover	VBF	Tree	5.9	5.9	5.9	0.0	0.0	5.9	0.00	1
214	Groundcover	Cleared Area	Cleared Area	0.0	25,464.1	1,038.4	2,912.6	8,482,954.6	222,220.7	5.10	2
6	Groundcover	Cleared Area	Harbor	0.4	338.7	159.2	132.7	17,612.8	955.3	0.02	2
87	Groundcover	Cleared Area	Structure	0.0	2,263.0	140.6	283.4	80,292.6	12,230.9	0.28	2
2	Groundcover	Harbor	Cleared Area	32.4	155.0	93.7	86.7	7,516.6	187.4	0.00	2
29	Groundcover	Harbor	Harbor	0.0	13,604.6	1,129.9	2,690.4	7,238,076.2	32,768.0	0.75	2
5	Groundcover	Harbor	Structure	2.7	37.4	11.6	14.5	211.3	58.0	0.00	2
30	Groundcover	Structure	Cleared Area	0.0	293.6	59.6	81.1	6,583.8	1,788.1	0.04	2
2	Groundcover	Structure	Harbor	5.9	22.3	14.1	11.6	134.4	28.2	0.00	2
118	Groundcover	Structure	Structure	0.0	2,376.6	245.3	442.5	195,771.9	28,949.9	0.66	2
281	Groundcover	Cleared Area	Groundcover	0.0	3,264.9	221.9	476.0	226,537.1	62,366.1	1.43	3
41	Groundcover	Cleared Area	Tree	0.1	575.6	111.1	145.1	21,041.8	4,553.5	0.10	3
32	Groundcover	Harbor	Groundcover	0.0	485.1	65.5	97.1	9,433.4	2,095.5	0.05	3
123	Groundcover	Structure	Groundcover	0.0	390.0	39.8	67.7	4,577.4	4,890.9	0.11	3
29	Groundcover	Structure	Tree	0.0	114.4	20.6	27.1	732.9	598.6	0.01	3
8	Groundcover	Harbor	River	5.3	288.8	138.8	110.5	12,219.1	1,110.5	0.03	4

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	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
8	Groundcover	Cleared Area	River	0.0	1,247.3	362.4	507.2	257,215.4	2,899.2	0.07	4
18	Groundcover	Structure	River	0.0	69.2	9.7	16.8	283.3	173.9	0.00	4
1	Groundcover	Substrate	Structure	90.2	90.2	90.2	0.0	0.0	90.2	0.00	5
362	Groundcover	Groundcover	Cleared Area	0.0	13,625.7	465.3	1,187.0	1,409,040.6	168,431.2	3.87	5
50	Groundcover	Groundcover	Harbor	0.1	1,909.9	251.8	376.0	141,383.3	12,592.0	0.29	5
383	Groundcover	Groundcover	Structure	0.0	5,231.3	221.3	470.5	221,405.3	84,756.8	1.95	5
1	Groundcover	Pond	Cleared Area	299.1	299.1	299.1	0.0	0.0	299.1	0.01	5
6	Groundcover	Substrate	Cleared Area	0.0	237.9	120.0	95.8	9,179.0	719.7	0.02	5
9	Groundcover	Substrate	Harbor	0.7	107.8	38.0	43.8	1,915.5	342.3	0.01	5
17	Groundcover	Substrate	Structure	0.2	77.9	28.1	24.6	603.1	478.1	0.01	5
83	Groundcover	Tree	Cleared Area	0.0	1,350.7	123.0	201.7	40,691.7	10,208.2	0.23	5
83	Groundcover	Tree	Structure	0.0	1,694.6	125.9	244.2	59,616.7	10,452.0	0.24	5
2	Groundcover	Groundcover	Groundcover	29.9	6,759.8	3,394.8	4,758.7	22,645,191.7	6,789.7	0.16	6
617	Groundcover	Groundcover	Groundcover	0.0	373,085.5	3,046.1	17,072.0	291,454,231.3	1,879,468.3	43.15	6
2	Groundcover	Groundcover	Pond	0.0	1,221.2	610.6	863.5	745,682.4	1,221.2	0.03	1
112	Groundcover	Substrate	Groundcover	0.2	13,943.7	493.0	1,444.0	2,085,069.2	55,218.5	1.27	7
2	Groundcover	VBF	Groundcover	0.1	0.2	0.2	0.1	0.0	0.3	0.00	7
2	Groundcover	Substrate	Backwater	266.6	432.8	349.7	117.5	13,805.8	699.4	0.02	7
2	Groundcover	Substrate	Groundcover	0.4	38.7	19.6	27.1	736.5	39.1	0.00	7
3	Groundcover	Backwater	Backwater	0.7	40.2	16.8	20.7	430.0	50.4	0.00	7
2	Groundcover	Backwater	Groundcover	1.4	2.7	2.0	0.9	0.8	4.1	0.00	7
179	Groundcover	Groundcover	River	0.0	18,730.1	854.3	2,242.9	5,030,823.8	152,928.2	3.51	7
8	Groundcover	Groundcover	VBF	6.2	3,793.8	623.3	1,305.5	1,704,412.0	4,986.4	0.11	7
29	Groundcover	River	River	0.0	4,052.1	217.8	749.0	560,953.1	6,316.4	0.15	7
3	Groundcover	Substrate	Backwater	55.7	3,091.1	1,197.9	1,651.2	2,726,373.3	3,593.7	0.08	7
126	Groundcover	Substrate	River	0.0	16,036.6	805.8	1,912.1	3,656,162.4	101,536.0	2.33	7
1	Groundcover	Substrate	Substrate	270.3	270.3	270.3	0.0	0.0	270.3	0.01	7
1	Groundcover	Substrate	VBF	41.4	41.4	41.4	0.0	0.0	41.4	0.00	7
20	Groundcover	Tree	River	0.4	586.6	101.9	173.1	29,951.8	2,037.7	0.05	7
4	Groundcover	Tree	VBF	0.0	401.9	180.1	210.7	44,399.2	720.5	0.02	7
8	Groundcover	VBF	River	0.0	264.7	76.3	109.6	12,020.8	610.8	0.01	7
3	Groundcover	VBF	VBF	0.0	62.5	20.8	36.1	1,300.3	62.5	0.00	7
2	Harbor	Cleared Area	Groundcover	5.5	92.5	49.0	61.5	3,784.0	98.0	0.00	8
30	Harbor	Groundcover	Groundcover	0.0	557.4	127.6	174.3	30,375.3	3,828.1	0.09	8

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	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
1	Harbor	Groundcover	Tree	73.2	73.2	73.2	0.0	0.0	73.2	0.00	8
15	Harbor	Harbor	Groundcover	0.0	1,473.5	164.8	378.5	143,261.7	2,471.6	0.06	8
1	Harbor	Structure	Groundcover	27.7	27.7	27.7	0.0	0.0	27.7	0.00	8
2	Harbor	Substrate	Groundcover	0.0	3.0	1.5	2.1	4.5	3.1	0.00	8
4	Harbor	Cleared Area	Cleared Area	15.6	1,123.8	604.9	459.9	211,535.8	2,419.8	0.06	9
4	Harbor	Cleared Area	Harbor	2.7	633.1	206.8	297.1	88,298.0	827.4	0.02	9
7	Harbor	Harbor	Harbor	502.8	27,055.0	8,643.0	11,054.4	122,199,249.9	60,501.3	1.39	9
4	Harbor	Harbor	Structure	12.0	30.3	24.9	8.7	75.8	99.7	0.00	9
4	Harbor	Substrate	Harbor	2.8	60.6	26.0	24.5	599.6	104.2	0.00	9
7	Harbor	Groundcover	River	0.0	868.8	231.0	370.0	136,910.4	1,616.7	0.04	14
3	Harbor	Harbor	River	43.0	366.2	169.5	172.7	29,824.8	508.4	0.01	14
1	Harbor	River	River	0.1	0.1	0.1	0.0	0.0	0.1	0.00	14
4	Harbor	Substrate	River	7.7	203.3	92.2	98.9	9,782.1	368.9	0.01	14
4	Harbor	Groundcover	Cleared Area	0.0	543.1	150.7	263.1	69,213.0	602.6	0.01	15
20	Harbor	Groundcover	Harbor	1.5	2,346.8	286.5	513.5	263,674.6	5,729.7	0.13	15
9	Harbor	Groundcover	Structure	0.2	382.2	52.3	124.6	15,531.3	470.4	0.01	15
5	Pond	Groundcover	Groundcover	13.1	322.3	119.9	130.1	16,928.2	599.5	0.01	1
3	Pond	Groundcover	Pond	0.8	55.8	33.4	28.9	834.6	100.3	0.00	1
2	Pond	Groundcover	Tree	1.9	8.4	5.2	4.6	20.7	10.3	0.00	1
6	Pond	Pond	Groundcover	1.4	809.1	225.7	338.8	114,793.7	1,354.4	0.03	1
1	Pond	Pond	Tree	350.4	350.4	350.4	0.0	0.0	350.4	0.01	1
1	Pond	Harbor	Harbor	3,183.9	3,183.9	3,183.9	0.0	0.0	3,183.9	0.07	2
1	Pond	Harbor	Groundcover	3.1	3.1	3.1	0.0	0.0	3.1	0.00	3
1	Pond	Groundcover	Harbor	176.0	176.0	176.0	0.0	0.0	176.0	0.00	5
2	Pond	Pond	Pond	2,155.8	11,615.0	6,885.4	6,688.6	44,737,778.3	13,770.8	0.32	6
14	Structure	Cleared Area	Groundcover	0.0	1,100.6	157.5	309.7	95,884.3	2,205.7	0.05	8
1	Structure	Cleared Area	Tree	82.6	82.6	82.6	0.0	0.0	82.6	0.00	8
56	Structure	Groundcover	Groundcover	0.1	856.9	139.5	180.5	32,590.7	7,810.1	0.18	8
12	Structure	Groundcover	Tree	0.6	113.7	45.1	38.6	1,487.7	541.0	0.01	8
2	Structure	Groundcover	VBF	0.2	31.0	15.6	21.8	474.8	31.3	0.00	8
30	Structure	Structure	Groundcover	0.0	498.6	45.8	103.3	10,673.2	1,373.8	0.03	8
1	Structure	Structure	Tree	355.7	355.7	355.7	0.0	0.0	355.7	0.01	8
6	Structure	Tree	Groundcover	0.1	96.0	28.8	35.0	1,227.5	173.1	0.00	8
6	Structure	Tree	Tree	0.0	131.5	63.1	58.9	3,472.1	378.6	0.01	8

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	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
1	Structure	Tree	VBF	57.0	57.0	57.0	0.0	0.0	57.0	0.00	8
18	Structure	Cleared Area	Cleared Area	0.1	1,467.4	189.8	342.2	117,092.3	3,417.3	0.08	9
7	Structure	Cleared Area	Structure	0.7	2,209.9	420.3	802.2	643,458.7	2,942.0	0.07	9
8	Structure	Structure	Cleared Area	1.5	276.4	65.8	94.9	9,015.3	526.5	0.01	9
40	Structure	Structure	Structure	10.9	4,680.8	1,347.8	1,190.1	1,416,456.8	53,910.1	1.24	9
1	Structure	River	River	161.3	161.3	161.3	0.0	0.0	161.3	0.00	14
1	Structure	Structure	River	1.6	1.6	1.6	0.0	0.0	1.6	0.00	14
2	Structure	Substrate	River	139.5	201.5	170.5	43.8	1,919.1	341.0	0.01	14
1	Structure	VBF	River	61.7	61.7	61.7	0.0	0.0	61.7	0.00	14
19	Structure	Groundcover	Cleared Area	3.9	599.4	105.3	138.0	19,046.0	2,001.3	0.05	15
20	Structure	Groundcover	Structure	0.1	195.9	44.2	53.3	2,843.1	884.3	0.02	15
1	Structure	Tree	Structure	0.0	0.0	0.0	0.0	0.0	0.0	0.00	15
5	Structure	Groundcover	River	0.2	244.7	88.5	98.8	9,758.9	442.5	0.01	16
124	Tree	Cleared Area	Cleared Area	0.2	15,859.4	1,552.1	2,466.1	6,081,557.1	192,460.5	4.42	2
6	Tree	Cleared Area	Harbor	0.0	1,503.1	291.7	596.3	355,531.8	1,750.0	0.04	2
63	Tree	Cleared Area	Structure	0.2	2,446.1	217.7	361.4	130,633.4	13,714.0	0.31	2
1	Tree	Harbor	Cleared Area	145.5	145.5	145.5	0.0	0.0	145.5	0.00	2
12	Tree	Harbor	Harbor	12.8	8,784.5	1,925.9	2,806.8	7,877,881.5	23,110.3	0.53	2
30	Tree	Structure	Cleared Area	0.1	197.0	39.3	55.4	3,070.0	1,178.4	0.03	2
4	Tree	Structure	Harbor	0.0	21.9	12.2	9.2	84.1	48.7	0.00	2
113	Tree	Structure	Structure	0.0	5,302.8	692.0	935.7	875,496.0	78,193.9	1.80	2
218	Tree	Cleared Area	Groundcover	0.0	2,617.9	226.1	420.3	176,641.4	49,295.7	1.13	3
71	Tree	Cleared Area	Tree	0.0	1,042.2	143.7	224.7	50,472.4	10,203.8	0.23	3
10	Tree	Harbor	Groundcover	0.5	223.7	72.1	73.6	5,419.9	720.5	0.02	3
1	Tree	Harbor	Tree	233.7	233.7	233.7	0.0	0.0	233.7	0.01	3
110	Tree	Structure	Groundcover	0.0	519.1	42.9	67.1	4,508.5	4,718.6	0.11	3
51	Tree	Structure	Tree	0.0	344.3	76.3	83.6	6,981.7	3,889.4	0.09	3
3	Tree	Structure	River	0.9	48.3	22.0	24.1	580.6	65.9	0.00	4
7	Tree	Structure	VBF	0.1	79.8	30.9	33.6	1,127.3	216.4	0.00	3
1	Tree	Groundcover	Cleared Area	972.2	972.2	972.2	0.0	0.0	972.2	0.02	5
1	Tree	Substrate	Cleared Area	23.0	23.0	23.0	0.0	0.0	23.0	0.00	5
2	Tree	Substrate	Harbor	31.5	261.9	146.7	162.9	26,542.6	293.5	0.01	5
12	Tree	Substrate	Structure	0.1	111.1	35.2	40.0	1,599.3	421.9	0.01	5
162	Tree	Tree	Cleared Area	0.0	13,725.8	739.0	1,837.1	3,375,065.1	119,711.0	2.75	5

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	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
2	Tree	Tree	Harbor	0.0	34.6	17.3	24.5	600.0	34.6	0.00	5
204	Tree	Tree	Structure	0.0	5,071.6	437.7	789.5	623,285.6	89,292.0	2.05	5
3	Tree	VBF	Structure	13.8	55.5	28.4	23.5	550.0	85.3	0.00	5
2	Tree	Tree	Tree	310.3	2,303.5	1,306.9	1,409.4	1,986,295.6	2,613.8	0.06	6
247	Tree	Tree	Tree	0.1	689,857.0	27,934.6	89,635.9	8,034,588,215.7	6,899,845.8	158.40	6
3	Tree	River	River	0.4	12.5	5.6	6.2	38.4	16.9	0.00	7
29	Tree	Substrate	Groundcover	0.0	1,794.3	304.3	396.3	157,056.5	8,826.0	0.20	7
25	Tree	Substrate	River	0.1	702.7	180.0	180.8	32,673.3	4,501.1	0.10	7
32	Tree	Substrate	Substrate	0.0	2,028.3	367.3	418.9	175,460.1	11,754.3	0.27	7
28	Tree	Substrate	Tree	0.2	604.2	123.4	142.7	20,375.6	3,456.2	0.08	7
36	Tree	Substrate	VBF	0.0	2,970.6	284.7	547.6	299,908.2	10,249.2	0.24	7
6	Tree	Tree	River	6.9	166.9	57.1	62.3	3,885.9	342.3	0.01	7
17	Tree	Tree	Substrate	0.0	1,644.4	456.3	504.6	254,599.9	7,756.9	0.18	7
49	Tree	Tree	VBF	0.0	9,074.5	1,075.3	2,386.9	5,697,448.0	52,690.3	1.21	7
9	Tree	VBF	Groundcover	0.3	775.6	266.0	259.3	67,210.7	2,394.2	0.05	7
15	Tree	VBF	River	2.0	502.2	180.4	180.0	32,390.0	2,705.6	0.06	7
34	Tree	VBF	Substrate	0.9	2,528.8	704.2	766.0	586,812.0	23,941.7	0.55	7
35	Tree	VBF	Tree	0.0	13,163.7	912.1	2,724.5	7,423,118.4	31,924.3	0.73	7
67	Tree	VBF	VBF	0.0	13,140.6	1,178.8	2,560.2	6,554,597.6	78,981.8	1.81	7
305	Tree	Groundcover	Cleared Area	0.0	6,314.9	350.0	725.0	525,641.6	106,753.7	2.45	10
22	Tree	Groundcover	Harbor	0.0	1,787.8	439.8	594.7	353,718.7	9,674.5	0.22	10
261	Tree	Groundcover	Structure	0.0	5,710.5	161.5	410.2	168,292.7	42,148.0	0.97	10
2	Tree	Groundcover	Tree	4,102.9	4,356.0	4,229.4	179.0	32,033.0	8,458.8	0.19	11
2	Tree	Groundcover	Groundcover	4.0	133.9	68.9	91.8	8,426.0	137.9	0.00	11
1	Tree	Groundcover	Tree	154.7	154.7	154.7	0.0	0.0	154.7	0.00	11
647	Tree	Groundcover	Groundcover	0.0	32,113.2	927.0	2,517.6	6,338,152.7	599,794.3	13.77	11
649	Tree	Groundcover	Tree	0.0	9,993.5	491.9	1,162.6	1,351,544.5	319,257.0	7.33	11
10	Tree	Groundcover	River	3.5	1,029.6	182.2	310.4	96,359.4	1,822.3	0.04	12
9	Tree	Groundcover	Substrate	0.6	1,142.2	146.3	374.6	140,360.1	1,316.3	0.03	12
21	Tree	Groundcover	VBF	6.3	1,986.5	503.5	550.6	303,114.0	10,572.8	0.24	12
602	Tree	Tree	Groundcover	0.0	21,088.2	766.0	1,951.0	3,806,550.9	461,139.3	10.59	13

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[a] Total number of polygons assessed to have this landcover class transition.

[b] Area of the smallest polygon assessed for this landcover class transition.

[c] Area of the largest polygon assessed for this landcover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:

1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.

2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)

3 = Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

4 = Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.

6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.

7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).

8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998.

9 = Impact, no change: originally impacted and remained impacted

10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.

11 = Natural-impact (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.

12 = Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.

13 = Natural-natural-impact (clearing): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.

14 = Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.

16 = Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.

15 = Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.

17 = Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.

18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

19 = River, unchanged: classified as a river for each year assessed.

Appendix C3.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for classes within the river channel for study area A, Kenai River.

	Landcover Class Assignment							Total Area		
Count of Polygons[a]	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	Variance Area	Sq. Feet	Acres	Transition Code[d]
3	River	Backwater	Backwater	298.1	2,685.1	1,492.9	1,424,358.2	4,478.6	0.10	7
3	River	Backwater	Groundcover	0.3	1.8	0.8	0.7	2.4	0.00	7
1	River	Backwater	River	365.7	365.7	365.7	0.0	365.7	0.01	7
5	River	Cleared Area	Cleared Area	16.4	90.6	53.5	1,065.9	267.5	0.01	2
5	River	Cleared Area	River	152.9	4,581.3	1,124.9	3,740,924.1	5,624.6	0.13	3
7	River	Groundcover	Backwater	0.0	1,528.0	406.2	294,507.4	2,843.7	0.07	7
1	River	Groundcover	Cleared Area	3.4	3.4	3.4	0.0	3.4	0.00	5
37	River	Groundcover	Groundcover	0.0	2,619.0	143.5	193,757.1	5,308.9	0.12	7
143	River	Groundcover	Groundcover	0.0	2,260.4	111.7	69,119.0	15,977.8	0.37	7
5	River	Groundcover	Harbor	1.4	62.2	18.9	657.9	94.5	0.00	5
39	River	Groundcover	River	0.0	785.0	137.2	28,750.5	5,349.4	0.12	7
179	River	Groundcover	River	0.0	13,738.8	769.3	3,187,536.0	137,699.9	3.16	7
45	River	Groundcover	Structure	0.0	765.0	46.9	20,826.4	2,109.5	0.05	5
1	River	Groundcover	Substrate	0.8	0.8	0.8	0.0	0.8	0.00	7
5	River	Groundcover	Tree	0.0	69.7	22.5	840.6	112.5	0.00	7
3	River	Groundcover	Tree	0.0	41.7	14.9	543.1	44.7	0.00	7
19	River	Groundcover	Tree	0.1	1,099.4	169.3	76,544.3	3,216.1	0.07	7
3	River	Harbor	Groundcover	0.1	36.3	20.8	348.0	62.4	0.00	3
3	River	Harbor	Harbor	5.5	564.3	285.2	78,056.0	855.6	0.02	2
11	River	Harbor	River	2.6	1,846.7	361.3	391,144.5	3,974.0	0.09	3
1	River	Harbor	Structure	5.0	5.0	5.0	0.0	5.0	0.00	2
1	River	Pond	Backwater	2.7	2.7	2.7	0.0	2.7	0.00	7
12	River	River	Groundcover	1.6	336.6	79.9	9,306.9	958.5	0.02	7
1	River	River	River	11,174,287.7	11,174,287.7	11,174,287.7	0.0	11,174,287.7	256.53	19
3	River	River	Structure	36.5	210.0	96.3	9,704.2	289.0	0.01	5
24	River	Structure	Groundcover	0.0	24.9	4.4	52.6	104.9	0.00	3
30	River	Structure	River	0.3	1,083.6	43.7	38,758.8	1,310.4	0.03	3
18	River	Structure	Structure	0.8	145.8	12.7	1,134.7	228.5	0.01	2
1	River	Structure	VBF	6.1	6.1	6.1	0.0	6.1	0.00	3
1	River	Substrate	Backwater	3,382.0	3,382.0	3,382.0	0.0	3,382.0	0.08	7

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	Landcover Class Assignment							Total Area		
Count of Polygons[a]	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	Variance Area	Sq. Feet	Acres	Transition Code[d]
22	River	Substrate	Groundcover	0.5	3,305.2	333.2	656,086.6	7,330.1	0.17	7
34	River	Substrate	Groundcover	0.0	4,035.4	346.4	660,723.0	11,778.8	0.27	7
70	River	Substrate	Groundcover	0.0	1,413.4	127.9	46,638.6	8,955.8	0.21	7
1	River	Substrate	Harbor	14.5	14.5	14.5	0.0	14.5	0.00	5
5	River	Substrate	River	33,589.3	304,577.6	121,875.6	11,393,659,992.4	609,378.2	13.99	7
74	River	Substrate	River	2.4	579,378.7	35,213.2	8,427,179,218.9	2,605,775.1	59.82	7
10	River	Substrate	Structure	0.3	79.9	29.8	564.8	298.2	0.01	5
3	River	Substrate	Substrate	62.4	27,620.0	10,928.7	215,302,800.2	32,786.2	0.75	7
3	River	Substrate	Substrate	45.4	538.3	215.3	78,339.0	645.8	0.01	7
1	River	Substrate	Tree	316.1	316.1	316.1	0.0	316.1	0.01	7
4	River	Substrate	Tree	0.6	596.2	194.8	74,324.8	779.3	0.02	7
6	River	Substrate	Tree	0.0	1,532.9	281.6	377,664.5	1,689.7	0.04	7
4	River	Substrate	VBF	1.3	104.2	57.5	1,988.2	230.1	0.01	7
1	River	Tree	Groundcover	0.1	0.1	0.1	0.0	0.1	0.00	7
4	River	Tree	River	0.0	90.3	43.7	2,413.6	174.8	0.00	7
1	River	Tree	Tree	22.7	22.7	22.7	0.0	22.7	0.00	7
1	River	Tree	Tree	0.1	0.1	0.1	0.0	0.1	0.00	7
2	River	VBF	Groundcover	31.7	44.5	38.1	82.5	76.3	0.00	7
45	River	VBF	River	1.6	6,411.8	713.9	2,362,171.7	32,125.3	0.74	7
2	River	VBF	Structure	9.1	21.2	15.1	72.0	30.3	0.00	5
9	River	VBF	VBF	0.1	1,161.3	174.2	141,114.6	1,568.2	0.04	7
1	Substrate	Groundcover	Groundcover	0.0	0.0	0.0	0.0	0.0	0.00	7
3	Substrate	Groundcover	Substrate	3.2	15.4	9.4	37.7	28.3	0.00	7
1	Substrate	Groundcover	Tree	5.4	5.4	5.4	0.0	5.4	0.00	7
7	Substrate	Groundcover	VBF	0.1	110.6	35.8	1,357.0	250.8	0.01	7
5	Substrate	River	River	0.4	174.6	41.4	5,666.7	207.0	0.00	7
1	Substrate	Substrate	Groundcover	14,971.3	14,971.3	14,971.3	0.0	14,971.3	0.34	7
1	Substrate	Substrate	Groundcover	58.2	58.2	58.2	0.0	58.2	0.00	7
1	Substrate	Substrate	River	22,873.2	22,873.2	22,873.2	0.0	22,873.2	0.53	7
2	Substrate	Substrate	River	0.1	21,589.2	10,794.7	233,044,444.9	21,589.4	0.50	7
31	Substrate	Substrate	River	0.7	5,744.2	676.1	1,497,720.4	20,959.5	0.48	7
1[e]	Substrate	Substrate	Substrate	2,853.1	2,853.1	2,853.1	0.0	2,853.1	0.07	17
26	Substrate	Substrate	Substrate	3.6	3,026.9	568.1	623,735.9	14,771.8	0.34	17

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	Landcover Class Assignment							Total Area		
Count of Polygons[a]	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	Variance Area	Sq. Feet	Acres	Transition Code[d]
6	Substrate	Substrate	Tree	0.3	194.0	57.5	6,585.7	344.8	0.01	7
36	Substrate	Substrate	VBF	0.6	3,409.6	537.8	527,596.0	19,361.7	0.44	7
1	Substrate	Tree	Substrate	6.9	6.9	6.9	0.0	6.9	0.00	7
4	Substrate	Tree	Tree	6.9	59.1	27.8	568.7	111.1	0.00	7
4	Substrate	Tree	VBF	2.2	401.3	112.4	37,263.7	449.6	0.01	7
11	Substrate	VBF	River	13.0	1,459.5	480.3	206,723.3	5,283.8	0.12	7
17	Substrate	VBF	Substrate	9.2	2,035.0	321.5	258,900.0	5,466.0	0.13	7
4	Substrate	VBF	Tree	9.2	5,363.7	1,374.8	7,072,990.7	5,499.3	0.13	7
23	Substrate	VBF	VBF	0.0	2,866.9	330.4	401,529.6	7,598.6	0.17	7
5	VBF	Cleared Area	Cleared Area	2.5	277.9	58.2	15,089.3	290.9	0.01	2
4	VBF	Cleared Area	Groundcover	4.7	459.7	231.0	34,814.1	924.2	0.02	3
1	VBF	Cleared Area	River	10.7	10.7	10.7	0.0	10.7	0.00	4
1	VBF	Cleared Area	Structure	11.8	11.8	11.8	0.0	11.8	0.00	2
3	VBF	Groundcover	Cleared Area	25.1	49.1	39.0	155.9	117.1	0.00	5
37	VBF	Groundcover	Groundcover	0.0	15,653.0	1,205.7	6,999,069.2	44,611.4	1.02	7
27	VBF	Groundcover	River	0.1	2,166.9	245.7	285,118.0	6,635.2	0.15	7
17	VBF	Groundcover	Structure	6.3	940.6	166.8	54,932.2	2,835.1	0.07	5
4	VBF	Groundcover	Substrate	1.9	139.0	43.9	4,098.8	175.6	0.00	7
30	VBF	Groundcover	Tree	0.0	8,766.5	1,004.5	4,685,766.8	30,135.4	0.69	7
8	VBF	Groundcover	VBF	0.3	460.4	88.6	26,127.1	708.6	0.02	7
26	VBF	River	River	0.0	555.3	134.7	25,324.3	3,502.9	0.08	7
7	VBF	Structure	Groundcover	0.4	53.8	19.1	392.7	133.5	0.00	3
3	VBF	Structure	River	1.4	74.6	36.7	1,344.0	110.0	0.00	4
7	VBF	Structure	Structure	5.6	310.7	62.7	12,108.0	438.9	0.01	2
1	VBF	Structure	Tree	36.9	36.9	36.9	0.0	36.9	0.00	3
6	VBF	Structure	VBF	0.0	48.2	22.3	447.4	133.9	0.00	3
1	VBF	Substrate	Cleared Area	111.0	111.0	111.0	0.0	111.0	0.00	5
21	VBF	Substrate	Groundcover	0.1	2,024.4	254.4	298,890.5	5,342.8	0.12	7
77	VBF	Substrate	River	0.0	5,145.8	479.7	790,123.8	36,938.4	0.85	7
6	VBF	Substrate	Structure	2.0	278.1	81.3	10,269.2	487.7	0.01	5
45	VBF	Substrate	Substrate	0.5	5,263.3	561.3	1,173,899.4	25,260.2	0.58	7
16	VBF	Substrate	Tree	0.0	1,441.7	234.6	175,686.0	3,753.3	0.09	7
61	VBF	Substrate	VBF	0.6	4,129.0	545.1	809,531.7	33,250.5	0.76	7
23	VBF	Tree	Groundcover	0.6	392.2	73.0	10,844.4	1,678.2	0.04	7

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	Landcover Class Assignment							Total Area		
Count of Polygons[a]	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	Variance Area	Sq. Feet	Acres	Transition Code[d]
5	VBF	Tree	River	21.8	605.4	174.9	60,369.8	874.7	0.02	7
3	VBF	Tree	Structure	17.6	87.9	52.7	1,233.6	158.0	0.00	5
3	VBF	Tree	Substrate	0.7	600.0	237.1	101,796.9	711.4	0.02	7
59	VBF	Tree	Tree	0.0	5,668.7	396.6	820,808.4	23,397.9	0.54	7
36	VBF	Tree	VBF	0.0	1,530.3	112.8	92,687.3	4,062.6	0.09	7
9	VBF	VBF	Groundcover	3.6	761.1	237.5	104,816.4	2,137.6	0.05	7
58	VBF	VBF	River	0.0	16,175.8	703.6	4,795,353.7	40,811.2	0.94	7
6	VBF	VBF	Structure	0.4	14.9	5.7	37.3	34.1	0.00	5
34	VBF	VBF	Substrate	0.2	3,218.3	444.7	418,448.5	15,119.0	0.35	7
26	VBF	VBF	Tree	0.0	7,750.1	507.6	2,331,091.2	13,197.9	0.30	7
55	VBF	VBF	VBF	0.1	13,303.6	1,327.6	5,548,824.0	73,019.3	1.68	18

[a] Total number of polygons assessed to have this landcover class transition.

[b] Area of the smallest polygon assessed for this landcover class transition.

[c] Area of the largest polygon assessed for this landcover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:
1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.
2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)
3 = Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.
4 = Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).
5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.
6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.
7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).
8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998
9 = Impact, no change: originally impacted and remained impacted
10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.
11 = Natural-impact (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.
12 = Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.
13 = Natural-natural-impact (clearing): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.
14 = Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.
16 = Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.
15 = Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.
17 = Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.
18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.
19 = River, unchanged: classified as a river for each year assessed.

[e] This polygon was assigned as both mainland and island substrate dependent upon year of assessment. For summary, it was not grouped with the next row of data which was consistently assigned as mainland substrate each year.

Appendix C4.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for islands in study area B, Kenai River.

	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
4	Groundcover	Groundcover	Groundcover	988.6	24,393.1	9,515.5	10,236.6	104,788,598.7	38,061.8	0.87	6
1	Groundcover	Groundcover	Tree	4,880.3	4,880.3	4,880.3	0.0	0.0	4,880.3	0.11	1
12	Groundcover	Groundcover	River	0.2	183.3	55.4	68.5	4,696.1	664.3	0.02	7
1	Groundcover	River	River	770.3	770.3	770.3	0.0	0.0	770.3	0.02	7
2	Groundcover	Substrate	Groundcover	281.3	405.9	343.6	88.1	7,762.0	687.3	0.02	7
2	Groundcover	Substrate	River	108.1	642.7	375.4	378.1	142,946.7	750.8	0.02	7
8	Groundcover	Substrate	Groundcover	0.1	202.1	35.0	69.2	4,795.1	279.6	0.01	7
10	Groundcover	Substrate	River	0.2	799.5	102.7	246.9	60,974.7	1,027.2	0.02	7
1	Groundcover	Tree	Tree	71.3	71.3	71.3	0.0	0.0	71.3	0.00	1
1	Tree	Tree	Tree	7,910.3	7,910.3	7,910.3	0.0	0.0	7,910.3	0.18	6
11	River	Groundcover	Groundcover	0.2	742.5	80.8	219.9	48,375.4	888.3	0.02	7
3	River	Groundcover	River	47.4	375.2	171.4	177.9	31,632.5	514.3	0.01	7
8	River	Substrate	Groundcover	1.6	429.2	122.6	150.2	22,550.6	980.8	0.02	7

[a] Total number of polygons assessed to have this landcover class transition.

[b] Area of the smallest polygon assessed for this landcover class transition.

[c] Area of the largest polygon assessed for this landcover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:

1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.
2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)
3 =Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.
4 =Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).
5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.
6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.
7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).
8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998
9 = Impact, no change: originally impacted and remained impacted.
10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.
11 = Natural-impact (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.
12 = Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.
13 = Natural-natural-impact (clearing): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.
14 = Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.
16 = Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.
15 = Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.
17 = Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.
18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.
19=River, unchanged: classified as a river for each year assessed.

Appendix C5.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for the mainland, study area B, Kenai River.

	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
1	Cleared Area	Tree	Tree	10.5	10.5	10.5	0.0	0.0	10.5	0.00	8
9	Cleared Area	Groundcover	Tree	0.0	672.5	165.8	258.3	66,738.1	1,492.0	0.03	8
1	Cleared Area	Substrate	Groundcover	1,502.3	1,502.3	1,502.3	0.0	0.0	1,502.3	0.03	8
2	Cleared Area	Cleared Area	Tree	113.1	1,544.6	828.8	1,012.2	1,024,596.7	1,657.7	0.04	8
4	Cleared Area	Cleared Area	Groundcover	1.4	4,192.1	1,193.8	2,004.2	4,016,770.8	4,775.3	0.11	8
5	Cleared Area	Groundcover	Groundcover	166.4	10,424.3	2,840.7	4,302.8	18,514,474.6	14,203.4	0.33	8
1	Cleared Area	Cleared Area	Structure	30.2	30.2	30.2	0.0	0.0	30.2	0.00	9
2	Cleared Area	Cleared Area	Cleared Area	1,086.4	2,532.1	1,809.3	1,022.2	1,044,978.0	3,618.6	0.08	9
2	Cleared Area	Substrate	River	75.1	539.2	307.2	328.2	107,701.6	614.3	0.01	14
5	Cleared Area	Groundcover	Cleared Area	0.0	394.8	190.6	143.8	20,689.9	953.1	0.02	15
322	Groundcover	Groundcover	Tree	0.0	36,115.3	764.7	3,276.3	10,733,820.3	246,238.2	5.65	1
420	Groundcover	Tree	Tree	0.0	21,769.4	75.6	1,076.5	1,158,927.4	31,751.5	0.73	1
8	Groundcover	Cleared Area	Cleared Area	17.1	8,757.0	2,693.4	2,710.1	7,344,625.7	21,547.2	0.49	2
3	Groundcover	Cleared Area	Structure	3.4	1,192.4	410.3	677.5	459,046.8	1,230.9	0.03	2
3	Groundcover	Structure	Structure	170.9	3,885.6	1,783.8	1,905.0	3,628,835.2	5,351.4	0.12	2
10	Groundcover	Cleared Area	Groundcover	14.6	26,739.2	3,381.7	8,332.8	69,436,047.3	33,817.0	0.78	3
3	Groundcover	Cleared Area	Tree	61.1	153.5	97.7	49.1	2,413.4	293.0	0.01	3
3	Groundcover	Structure	Groundcover	6.6	158.4	60.3	85.0	7,229.2	181.0	0.00	3
3	Groundcover	Cleared Area	River	3.4	651.6	349.6	326.3	106,500.2	1,048.7	0.02	4
27	Groundcover	Groundcover	Cleared Area	0.0	8,006.0	735.3	1,647.1	2,712,858.0	19,852.8	0.46	5
22	Groundcover	Groundcover	Structure	2.9	801.0	161.0	221.3	48,971.7	3,541.6	0.08	5
1	Groundcover	River	Structure	1.4	1.4	1.4	0.0	0.0	1.4	0.00	5
1	Groundcover	Substrate	Cleared Area	49.1	49.1	49.1	0.0	0.0	49.1	0.00	5
13	Groundcover	Substrate	Structure	1.1	375.4	97.9	118.9	14,138.3	1,273.1	0.03	5
16	Groundcover	Tree	Cleared Area	0.0	941.9	76.4	239.5	57,357.2	1,222.6	0.03	5
9	Groundcover	Tree	Structure	0.0	372.1	65.8	122.9	15,114.5	592.1	0.01	5
64	Groundcover	Groundcover	Groundcover	0.0	322,783.9	14,786.1	43,661.5	1,906,325,827.7	946,309.0	21.72	6
51	Groundcover	Groundcover	River	0.0	4,081.0	451.9	991.2	982,571.4	23,048.2	0.53	7
10	Groundcover	River	River	1.1	1,586.9	340.1	558.9	312,361.9	3,400.8	0.08	7
50	Groundcover	Substrate	Groundcover	0.0	15,917.3	1,679.3	3,026.1	9,157,521.8	83,965.7	1.93	7
64	Groundcover	Substrate	River	0.0	11,040.9	756.2	1,784.6	3,184,651.1	48,398.2	1.11	7
6	Groundcover	Substrate	Tree	7.5	617.2	160.7	238.4	56,843.9	964.3	0.02	7
6	Groundcover	Tree	River	0.0	0.3	0.1	0.1	0.0	0.9	0.00	7
306	Groundcover	Tree	Groundcover	0.0	3,220.6	20.4	190.5	36,295.4	6,227.7	0.14	13
22	Tree	Cleared Area	Cleared Area	17.9	3,811.3	1,191.9	1,043.0	1,087,816.4	26,221.2	0.60	2
6	Tree	Cleared Area	Structure	90.2	2,244.8	578.9	831.0	690,487.3	3,473.3	0.08	2

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Count of	Landcover Class Assignment 1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Total Area Sq. Feet	Acres	Transition
1	Tree	Structure	Cleared Area	82.8	82.8	82.8	0.0	0.0	82.8	0.00	2
4	Tree	Structure	Structure	33.7	4,227.6	1,162.4	2,047.4	4,191,930.4	4,649.5	0.11	2
19	Tree	Cleared Area	Groundcover	0.0	2,418.4	319.4	591.2	349,511.3	6,068.1	0.14	3
7	Tree	Cleared Area	Tree	0.4	251.2	102.2	111.0	12,311.6	715.3	0.02	3
2	Tree	Structure	Groundcover	30.7	159.1	94.9	90.8	8,238.6	189.8	0.00	3
1	Tree	Structure	Tree	23.5	23.5	23.5	0.0	0.0	23.5	0.00	3
91	Tree	Tree	Cleared Area	0.2	10,484.1	1,890.3	2,453.4	6,019,409.1	172,020.7	3.95	5
101	Tree	Tree	Structure	5.1	5,334.2	1,065.2	1,224.0	1,498,087.5	107,588.4	2.47	5
55	Tree	Tree	Tree	1.2	222,509.1	36,805.9	50,626.4	2,563,029,364.1	2,024,322.9	46.47	6
1	Tree	Substrate	Groundcover	14.9	14.9	14.9	0.0	0.0	14.9	0.00	7
1	Tree	Tree	River	938.2	938.2	938.2	0.0	0.0	938.2	0.02	7
45	Tree	Groundcover	Cleared Area	0.0	8,854.7	1,050.0	1,949.3	3,799,638.2	47,248.9	1.08	10
34	Tree	Groundcover	Structure	0.0	1,656.3	211.1	349.7	122,321.0	7,176.9	0.16	10
440	Tree	Groundcover	Groundcover	0.0	38,639.8	320.6	2,045.1	4,182,512.0	141,051.0	3.24	11
479	Tree	Groundcover	Tree	0.0	45,740.6	215.8	2,167.2	4,696,744.1	103,378.8	2.37	11
1	Tree	Pond	Cleared Area	1,578.0	1,578.0	1,578.0	0.0	0.0	1,578.0	0.04	11
5	Tree	Groundcover	River	0.1	1.0	0.4	0.4	0.2	2.0	0.00	12
471	Tree	Tree	Groundcover	0.0	25,179.4	881.1	2,834.7	8,035,445.3	415,011.9	9.53	13

[a] Total number of polygons assessed to have this landcover class transition.

[b] Area of the smallest polygon assessed for this landcover class transition.

[c] Area of the largest polygon assessed for this landcover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:

1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.

2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.).

3 = Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

4 = Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.

6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.

7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).

8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998.

9 = Impact, no change: originally impacted and remained impacted.

10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.

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11 = Natural-impact (clearing)-recovering: trees (1975 and groundcover (1985); but remaining vegetated as groundcover or trees by 1998.

12 = Natural-impact (clearing)-river/substrate: trees (1975) and groundcover (1985); transitioned to river or substrate by 1998.

13 = Natural-natural-impact (clearing): trees in 1975 and 1985, but groundcover in 1998; possibly indicating land clearing activities.

14 = Impact-river/substrate: impacted in 1975 and later was classed as river or substrate.

16 = Impact-recovering-river/substrate: impacted in 1975 and revegetated in 1985, but eroded to river or substrate in 1998.

15 = Impact-recovering-impact: impact in 1975 and revegetated by 1985, but impacted again in 1998.

17 = Substrate, unchanged: gravel faced banks and visible stream bottom in 1975 that remained unchanged in 1985 and 1998.

18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

19 = River, unchanged: classified as a river for each year assessed.

Appendix C6.–Summary data for tracking landcover class transition between years (1975, 1985, and 1998) for classes within the river channel, study area B, Kenai River.

	Landcover Class Assignment								Total Area		
Count of	1975	1985	1998	Min Area[b]	Max Area[c]	Ave Area	SD Area	Variance Area	Sq. Feet	Acres	Transition
2	Substrate	Substrate	Substrate	76.3	211.0	143.7	95.2	9,060.2	287.3	0.01	17
26	River	Groundcover	Groundcover	0.0	3,872.4	334.5	866.0	749,966.7	8,698.2	0.20	7
29	River	Groundcover	River	0.2	15,039.0	1,402.2	3,031.9	9,192,135.4	40,664.0	0.93	7
1	River	Groundcover	Tree	0.5	0.5	0.5	0.0	0.0	0.5	0.00	7
3	River	River	Groundcover	3.6	57.5	22.6	30.3	916.7	67.7	0.00	7
1	River	River	Substrate	17.1	17.1	17.1	0.0	0.0	17.1	0.00	7
4	River	Substrate	Groundcover	14.2	255.5	105.1	109.7	12,038.2	420.4	0.01	7
58	River	Substrate	Groundcover	0.0	768.7	122.1	169.1	28,582.2	7,081.0	0.16	7
1	River	Substrate	River	58,654.2	58,654.2	58,654.2	0.0	0.0	58,654.2	1.35	7
13	River	Substrate	River	14.0	171,072.1	25,655.5	46,711.2	2,181,934,727.8	333,521.5	7.66	7
4	River	Substrate	Substrate	0.0	9.8	2.5	4.8	23.4	10.0	0.00	7
1	River	Tree	Groundcover	6.2	6.2	6.2	0.0	0.0	6.2	0.00	7
1	Substrate	River	River	14.5	14.5	14.5	0.0	0.0	14.5	0.00	7
1	Substrate	River	Substrate	14.5	14.5	14.5	0.0	0.0	14.5	0.00	7
4	Substrate	Substrate	River	1.5	7.0	4.2	2.7	7.5	16.6	0.00	7
3	River	Groundcover	Structure	11.1	97.8	45.7	45.9	2,107.7	137.0	0.00	5
5	River	Substrate	Structure	0.3	80.4	34.0	32.1	1,030.9	169.8	0.00	5
1	River	Area	River	220.7	220.7	220.7	0.0	0.0	220.7	0.01	3
1	River	River	River	4,526,600.7	4,526,600.7	4,526,600.7	0.0	0.0	4,526,600.7	103.92	19

[a] Total number of polygons assessed to have this cover class transition.

[b] Area of the smallest polygon assessed for this cover class transition.

[c] Area of the largest polygon assessed for this cover class transition.

[d] Transition codes were created to allow grouping of similar classes for summarizing data:

1 = Successional: maturing vegetation, such as groundcover to trees. Not trees to groundcover. Includes apparent natural water/shoreline interface changes.

2 = Natural-impact-impact: the 1975 vegetation class transitioned to some permanent human impact (area, structure, harbor, etc.)

3 = Natural-impact-recovering: the 1975 vegetation class transitioned to some type of human impact, but then revegetated by 1998.

4 = Natural-impact-river: the 1975 vegetation class transitioned to some type of human impact and later to river (erosion?).

5 = Natural-natural-impact: the 1975 vegetation class remained vegetation thru 1985 and later received some type of human impact.

6 = Natural, no change: the 1975 vegetation class was unchanged through the study period.

7 = Shoreline transitions: reflects changes occurring near the waterline (classes moving between vegetation, substrate, river, vegetated bank face).

8 = Impact-recovering: impact in 1975 and recovering in 1985 and 1998.

9 = Impact, no change: originally impacted and remained impacted.

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10 = Natural-impact (clearing)-impact: trees (1975) and groundcover (1985), possibly indicating land clearing activities; later classed as impacted.

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18 = Vegetated bank face: vegetation below the bankline in 1975 that remained unchanged in 1985 and 1998.

19 = River, unchanged: classified as a river for each year assessed.

APPENDIX D: MEASUREMENT ERROR

Appendix D1.–Summary data for characteristics and area of selected structures measured in aerial photographs versus on the ground, Kenai River, 1998.

Structure I.D. #	Area (sq ft) Photo	On Ground Trial 1	On Ground Trial 2	Percent Error Trial	Percent Error Trial 2	No. of Sides[a]	No. of Stories[b]	No. of Roof Lines	Canopy /Wash Out[c]	Complexity[d]
2	2,529	2,778	2,619	-9	-3	6	1.0	2	1	10
5	2,150	2,320		-7		14	2.0	6	0	22
6[a]	2,377	2,345		1		6	2.0	6	0	14
6[b]	128	140		-9		4	0.5	1	1	7
7	1,073	1,065		1		4	1.0	1	0	6
14	2,330	2,280		2		9	1.0	1	0	11
17	1,897	1,920		-1		4	0.0	0	0	4
18	967	1,010		-4		4	1.0	1	0	6
19	2,073	2,177		-5		4	2.0	5	0	11
19[a]	127	141		-10		4	0.5	1	1	7
23	3,282	3,426	3,363	-4	-2	12	1.0	1	0	14
24	1,755	1,902		-8		4	2.0	4	0	10
25	1,579	1,683		-6		12	2.0	1	0	15
25[a]	220	256		-14		4	1.5	1	1	8
26	831	823		1		4	1.0	1	1	7
28	717	801		-10		4	1.0	1	1	7
30	954	1,107	1,096	-14	-13	4	1.0	2	1	8
30[a]	1,495	1,570	1,511	-5	-1	4	0.0	0	0	4
40	4,938	4,700		5		17	1.0	4	0	22
51	2,548	2,812	2,560	-9	0	14	1.0	2	1	18
52	948	933		2		8	2.0	2	0	12
53[a]	1,913	1,793		7		12	2.0	1	0	15
53	3,287	3,679		-11		12	2.0	2	1	17
54	3,197	3,335		-4		12	2.0	3	1	18
58	331	374		-11		4	1.0	1	0	6
62	1,438	1,587	1,532	-9	-6	4	1.0	2	1	8
63	425	459		-7		4	1.0	1	0	6
64	655	715		-8		8	1.0	1	1	11
65	594	563		6		4	1.0	1	1	7
66	199	214		-7		4	0.5	1	1	7
67	1,027	986		4		4	1.0	1	1	7
68	1,333	1,439		-7		4	1.5	1	1	8
69	2,352	2,082		13		12	2.0	3	1	18

[a] Number of measured sides of the structure to include walls, decks, staircases, etc.

[b] Number of stories for the structure were valued as:

0=foundation.

0.5= shed, play house, etc.

1, 2 = normal house story.

1.5= house with daylight basement.

[c] A value of 1 was given to any structure with a partial canopy cover or when light washed out aspects of the photography.

A value of 0 was given if roof view was clear.

[d] Complexity is the sum of all the values for the structure's characteristics.