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Steelhead Habitat Capability Pilot Study

Phase I: Remote Sensing/GIS Acquisition, and On-ground Stream Habitat Characterization Surveys in the Sitkoh Creek Watershed

by

Anthony P. Crupi

Jeff V. Nichols

Brian J. Frenette

and

Randall S. Mullen

December 2010

Alaska Department of Fish and Game **Division 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)

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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Anthony P. Crupi
Division of Sport Fish, Douglas

Jeff V. Nichols
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Brian J. Frenette
Division of Sport Fish, Douglas

and
Randall S. Mullen
215 West Lamme Street, Bozeman, MT 59715

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

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Anthony P. Crupi,
Alaska Department of Fish and Game, Division of Sport Fish,
PO BOX 110024 Juneau, AK 99811-0024, USA

Jeff V. Nichols[a]*,*
Alaska Department of Fish and Game, Division of Sport Fish
PO BOX 110024 Juneau, AK 99811-0024, USA

Brian J. Frenette,
Alaska Department of Fish and Game, Division of Sport Fish
PO BOX 110024 Juneau, AK 99811-0024, USA
and
Randall S. Mullen,
215 West Lamme Street, Bozeman, MT 59715, USA

Author to whom all correspondence should be addressed: jeff.nichols@alaska.gov

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ABSTRACT

This report describes the initial groundwork for creating a model to assess the carrying capacity of steelhead *Oncorhynchus mykiss* in Southeast Alaska streams. During 2005 we conducted stream habitat surveys on Southeast Alaska's Chichagof Island in the Sitkoh Creek watershed and acquired a high-resolution digital imagery dataset using low-elevation digital photography. Combining these data, we mapped the stream network of Sitkoh Creek and updated the regional GIS hydrography layer. Several stream reach characteristics such as channel bed width, gradient, and incision were used to classify 43 individual stream reaches according to channel type and fluvial process group. The collection of additional habitat parameters, including the density of large woody debris, macro-pools, and riparian disturbance patterns, provided additional information for each of these stream reaches.

Fundamental to the analysis of this dataset is the desire to better understand the role played by the combination of stream reach characteristics as they contribute to the formation of important fish habitat features such as accumulations of large wood and macro-pools. Consistent with other studies, we found that as channel bed width increased and gradient decreased, we observed higher counts of large wood and macro-pools and density of large wood accumulations increased. We also observed higher counts and densities of key wood as gradient and incision increased.

Key words: carrying capacity, habitat, large wood accumulations, low-elevation digital photography, macro-pools, *Oncorhynchus mykiss*, Sitkoh Creek, steelhead, stream habitat survey.

INTRODUCTION

The long-term goal of this project is to develop a habitat-based steelhead *Oncorhynchus mykiss* carrying capacity model which integrates stream habitat information with escapement estimates from a companion steelhead trout production study. This project was initiated in the Sitkoh Creek watershed with an assessment of the habitat and the use of various habitats by juvenile and adult steelhead. Resource agencies charged with managing salmon have primarily relied on two stock assessment methods to estimate total escapement, and ultimately the harvestable surplus (Bocking and Peacock 2004; Der Hovanisian and Geiger 2005). The first approach relies on mark-recapture tagging projects, aerial survey data, weir enumeration, and biological data from multiple years across multiple river systems to estimate escapement through spawner-recruit models (McPherson and Carlisle 1997; Geiger and McPherson 2004). An alternative method, used by researchers in British Columbia, is a habitat-based model that uses habitat characteristics and smolt statistics to estimate the number of spawners required to produce the maximum smolt yield, or production capacity (Tautz et al. 1992; Bocking and Peacock 2004).

This alternative approach for steelhead stock assessment involved quantifying the amount of available rearing habitat within the Skeena River drainage, and using this information to model smolt production estimates (Tautz et al. 1992). This model was developed on data specific to 3 categories: distribution, fish use, and production. Distribution referred to the number and extent of streams or tributaries likely to contain steelhead; fish use involved estimating total area and total usable area of steelhead-bearing streams; and production referred to the estimation of the number of steelhead smolts produced from the streams identified usable area (i.e., steelhead smolt/km of usable habitat). Because empirical production estimates were not available, several models using data collected on other systems were employed to obtain an estimate of carrying capacity for the Skeena River. Their efforts lay the groundwork for exploring patterns between freshwater stream habitats and carrying capacity. Ultimately, our goal is to test Tautz's approach and develop a habitat-based model for estimating the carrying capacity of steelhead in watersheds of Southeast Alaska (SEAK) in the absence of specific stock assessment.

This report details activities associated with the first of 4 phases for developing a habitat-based steelhead carrying capacity model for the Sitkoh Creek watershed. Phase I activities began with an inventory and assessment of the stream habitat found in the Sitkoh Creek watershed. Additional activities included remote-sensed image acquisition, and integration of all watershed habitat data into Geographic Information System (GIS). Phase II activities include identifying steelhead trout useable habitat throughout the watershed. Phase III activities require data from a concurrent steelhead trout production study and stock assessment for the Sitkoh Creek watershed. The final phase (IV) will integrate information from the previous three phases and develop a steelhead habitat capability model, providing estimates of carrying capacity.

The stream habitat survey protocol used in this first phase of this multi-stage project provided a means for documenting the current channel and riparian condition at the individual reach scale. Attributing geographic spatial data (i.e., latitude/longitude coordinates) to physical and biological information allowed full integration with a GIS, and enhanced our ability to conduct more meaningful landscape-level resource assessments. Fundamental to our exploratory analysis (post hoc) in this report was the question, "What landscape forming processes propagate steelhead habitat?" We assessed the contribution of several stream reach characteristics (channel bed width, gradient, and incision) to the accumulations of large woody debris (large and key wood) and the formations of macro-pools, as these features are known to provide important elements of fish habitat (Beechie and Sibley 1997; Cederholm et al. 1997; Johnson et al. 2005; Morris et al. 2006).

OBJECTIVES

Phase I (Habitat Characterization) objectives that were addressed in pursuit of the overall goal:

1. Measure and characterize physical stream habitat in the mainstem and tributaries of the Sitkoh Creek watershed, including collection of geographic coordinate data for integrating with GIS (Geographic Information System);
2. Identifying areas within the mainstem and various tributaries of the watershed used by spawning adult steelhead;
3. Integrating information generated from Objectives 1-2 to develop detailed maps of project area, and classify the watershed into the different physical habitat types.

STUDY AREA

The Sitkoh Creek watershed is a highly productive lake system located on Chichagof Island in SEAK near western Chatham Strait (Figure 1). The Alaska Department of Fish and Game, Division of Sport Fish (ADF&G-SF) operated a immigrant/emigrant weir at the mouth of Sitkoh Creek, and technicians counted 679 and 764 immigrating adult steelhead in 2003 and 2004 respectively (Love and Harding 2008). Outmigrating steelhead smolt were also counted in these years totaling 3,162 and 3,742 respectively. Sea-run cutthroat trout *Oncorhynchus clarki* and Dolly Varden *Salvelinus malma* migrating downstream through the weir were also counted, totaling 4,588 and 4,095 cutthroat, and 52,884 and 62,409 Dolly Varden in 2003 and 2004, respectively.

The watershed drains 4,973 hectares (ha) before emptying into Sitkoh Bay with a mapped stream network, including Sitkoh Lake (approximately 200 ha), totaling approximately 111 km. Slightly more than half of the stream network length (approximately 52%) is mapped and classified as high-gradient headwater streams that empty directly into the lake. The remaining stream network includes the mainstem outlet stream (approximately 6 km) and over 50 km of lower gradient 2nd order tributaries. Nearly 19% of the watershed has been managed for timber harvest (Figure 2). A thorough synopsis of watershed statistics prior to our stream habitat surveys is included in Appendix A.

Sitkoh Creek is an important freshwater steelhead stream in the Sitka Management Area (Jones et al. 1991; Schmidt 1992). The United States Forest Service (USFS) maintains 2 popular public-use cabins on Sitkoh Lake, with visitor access to the watershed primarily by floatplane, boat and all-terrain vehicle (ATV). Numerous logging roads provide additional access to land within the upper watershed.

The mainstem of Sitkoh Creek (ADF&G Anadromous Waters Catalog Stream No. 113-59-10040) is a lake-fed outlet stream occupied by most salmonid species found in the region, except for Chinook salmon *Oncorhynchus tshawytscha*. Channel bed widths in the mainstem of Sitkoh Creek range from 10 to 30 m wide, and depth typically varies between 0.1 m and 3 m.

METHODS

STREAM HABITAT SURVEYS

Following established stream habitat survey protocols (Frenette et al. *unpublished a*), the mainstem of Sitkoh Creek and the prioritized tributaries within the watershed were surveyed during May 2005. The core components of the stream habitat survey protocol used in the present study were derived from the USFS Region 10 Tier II Aquatic Habitat Survey (USFS 2001), and the USFS Channel-type Users Guide (USFS 1992). The stream habitat survey provided key data necessary for conducting coarse assessments of the habitat that may be important to fish at both the watershed and geomorphic reach scales. The stream habitat survey methodology included the collection of both physical and biological features and/or events encountered while transiting along the stream network. The locations of these features/events were recorded on Global Positioning Satellite (GPS) receivers, adding the necessary spatial data for full integration with a GIS, using ArcGIS software (Version 9.1, ESRI 2005).

The underlying unit of scale at which physical habitat parameter statistics were aggregated and reported for the stream habitat survey method used in this project was the geomorphic stream reach (stream reach, hereafter) level. Identification of distinct reaches was synonymous with the stream classification system used to describe geomorphically distinct stream segments in the context of the watershed, or better known as the “Tongass Channel-type Classification” system. This classification scheme was based on the geomorphic process groups, which “describe the interrelationship between watershed runoff, landform relief, geology, and glacial or tidal influences on fluvial erosion and deposition processes”. Individual stream reaches have a minimum mapping unit or length of 100 m; further, they are generally homogeneous throughout their length with regard to macro-habitat characteristics. Therefore, individual stream reaches were classified by the physical attributes found within their geomorphic boundaries (Frenette et al. *unpublished a*).

Data collected to achieve this objective included: (1) mapping the stream course; (2) mapping physical habitat features; (3) characterizing physical habitat of stream reaches and side- channels; and (4) documenting features/events with photos. Physical habitat measures recorded within each reach include: stream gradient; channel bed width; incision depth; bankfull width; predominant bank composition; channel pattern; dominant substrates (primary, secondary and tertiary); length of stream reach; length of side-channel(s); length of riparian disturbance (by type); number of barriers (by type); number of large woody debris (LWD) accumulations; number of key-wood pieces; and counts of macro-pools (Appendix B).

All data collected during this project were entered into the respective module of the division's *Odyssey* database following established protocols (Frenette et al. *unpublished b*), and handled identically with respect to data processing and quality assurance/control measures.

Calculated metrics include mean channel bed width.

Mean channel bed width ($\overline{cbw}_i$) for each reach is calculated as:

$$\overline{cbw}_i = \frac{\sum cbw_k}{n_i} \tag{1}$$

where:

cbw_k = individual channel bed width measures taken within reach i; and

n_i = number of measures taken within reach i.

Censused metrics include: macro-pool density; large-wood accumulation density; and key-wood density.

Mean adult steelhead density (A_i) for each reach was calculated as:

$$A_i = \frac{\sum a_i}{l_i} \tag{2}$$

where:

a_i = number of adult steelhead counted in reach i; and

l_i = length of reach i.

Macro-pool density (D_i) for each reach will be calculated as:

$$D_i = \frac{p_i}{l_i} \tag{3}$$

where:

p_i = number of qualifying macro-pools counted in reach i; and

l_i = length of reach i.

Large-wood density (L_i) and key-wood density (K_i) for each reach will be calculated the same as in the macro-pool density calculation (2) above. Density data in this report is presented as a ratio of the counts scaled to the length of the reach. While we acknowledge that densities are typically calculated based on area this approach was defined in the operational plan. For comparative purposes we recommend limiting references to stream reaches of similar CBW. Therefore, the mainstem reaches for example, would provide meaningful interpretation of density data.

SURVEYS TO IDENTIFY SPAWNING AREAS

The use of Sitkoh Creek tributaries by adult steelhead for spawning, as well as use by juveniles and fry for rearing, was previously unknown. Therefore, stream habitat survey data and GIS tools were used to locate prioritized tributaries (based on length and stream process group) and then visited during the peak of the adult steelhead spawning migration. Foot surveys focused on searching for adult steelhead using polarized sunglasses while walking up the prioritized tributaries from the confluence with the mainstem or lake, and continuing upstream to the point where anadromous fish migration appeared to end (e.g., substantial barrier, gradient measuring ≥ 24%, no scoured channel bed). The number of steelhead observed, their activity (spawning, holding, unknown) and a geographic coordinate were collected when and where adult steelhead were observed.

We also collected steelhead location and count data on the mainstem of Sitkoh Creek during 2 steelhead abundance index snorkel surveys. It is important to note that the data collected during these surveys only represent locations where steelhead were observed and do not account for observer bias and/or calibration factors associated with abundance estimates. These issues will be addressed by the stock assessment project (i.e., Love and Harding 2009).

LEDP (REMOTELY-SENSED DATA)

Remote-sensing techniques have been successfully used to document landscape level changes in habitat, and to conduct large-scale inventories of habitat features on the ground that could not have been conducted through other means (Puestow et al. 2001; Weber and Dunno 2001). We used a low-elevation digital photography (LEDP) system to obtain high-resolution base layer imagery (30cm and 60cm resolution) of the entire Sitkoh watershed, including the stream networks associated with the lake tributaries, and the mainstem outlet stream. This photography system not only provides excellent multi-spectral imagery for helping to identify macro-habitat features from the air, but it also offers a baseline dataset depicting current conditions within the watershed which can be used for detection of habitat changes in the future (e.g., evidence of catastrophic landslide events, updating land-use practices such as timber management, distribution of large accumulations of wood, etc). A detailed description of the LEDP system hardware and software components, along with technical instructions is described in Nichols and Frenette (*unpublished).*

Before our LEDP acquisition flights, base layer imagery for the project area was limited to United States Geological Survey (USGS) quarter-quad maps, and digital ortho-photograph quads (DOQ's). Although USGS quad maps provide topographical interpretations of the watershed, they lack sufficient detail needed for macro-habitat assessment. The USFS DOQ's have similar shortcomings in that they are panchromatic (i.e., black and white), were acquired in 1997, and have a ground resolution of 2 meters.

LEDP acquisition flights coincided with ADF&G weir operations and steelhead index snorkel surveys, resulting in imagery that reflects current hydrological patterns during known flow levels. Existing DOQ image catalogs assisted in creating flight lines and imagery footprints that guided LEDP flights of the watershed (Figure 3). Post-processing of the LEDP imagery was conducted in house by SF staff and by Jim Nichols of Terra-Mar using proprietary software

(Terra-Mar 1995-2005). Post-processing of imagery and associated spatial data acquired during the flight, yields highly accurate rectified ortho-photos and photo-mosaics; however, technical malfunctions and circumstances in SEAK have inhibited the ability to provide seamless photo-mosaics, such as found in the USFS DOQ image catalog. Although lacking the completely seamless appearance of other lower-resolution image catalogs, the LEDP DOQ's and photo-mosaics can now be displayed digitally using GIS software, and these data were instrumental in creating base layer maps and identifying stream hydrography.

EXPLORATORY DATA ANALYSES

We performed exploratory (post hoc) analyses to assess the relationships between measured stream reach characteristics and habitat characteristics such as large woody debris accumulation and macro-pool formation. Although these exploratory analyses are not intended to be confirmatory in nature, they may provide information useful for describing relationships between habitat features and associated reach characteristics. The 3 reach characteristics (independent variables) included channel bed width, gradient, and incision. The 6 dependent habitat characteristic variables assessed for each reach included: large wood counts and density; key wood counts and density; and macro-pool counts and density. We employed several statistical techniques in the analysis of this dataset, including tests for normality, correlation matrices, multiple regression, principal components analysis, and canonical correlation analysis following established procedures (Johnson 1998). We used the SAS® statistical package (SAS Institute 9.1, Cary, NC, USA) for all data analyses with statistical significance selected at $\alpha < 0.05$. We tested the data for deviations from normality by assessing the dataset through box plots, histograms, normal probability and residual plots. There were a few minor deviations from normality though the majority of data were homoscedastic. Hence, we maximized interpretability of the data by not using the log transformed data, which only mildly improved the normality of the variable incision. As well, it was assumed that the probability of detecting wood and pools was random and that each feature had equal chance of detection.

We computed Pearson product-moment correlation coefficients to evaluate relationships between strongly correlated variables. These provided potential evidence for relationships between independent and dependent variables. We recognized limitations of regression techniques given the multidimensionality of the data; therefore, we employed multivariate methods designed for such complexity.

Principal components analysis was performed first to assess and determine which variables captured the majority of the variability. A principal components analysis is also useful for data exploration, detection of possible outliers, and depiction of the data's "true dimensionality" (Johnson 1998). We then used canonical correlation analysis to identify linear combinations between the set of independent and dependent variables. Canonical correlation generally finds a small number of linear transformations from each set of variables that maximize the correlation coefficient between predictor and response variates (Johnson 1998). The plot of these canonical variables was useful in assessing multivariate dependencies. The correlations (ρ_c) were interpreted through the assessment of the coefficients' weights and loadings. We interpreted coefficients greater than $|0.4|$. The canonical R_c^2, signified the proportion of variance in habitat characteristics that was contributed by the explanatory reach characteristic variables. We also performed a canonical redundancy analysis to determine how well the newly created set of canonical variables predicted the original variables.

We also assessed the locations where adult steelhead were observed during the abundance index snorkel surveys by conducting a hot-spot analysis. Following procedures outlined by ESRI (2005) and ESRI staff during a Spatial Statistics seminar (ESRI 2006), we used the ArcGIS toolbox Spatial Autocorrelation (Moran's I) tool to identify the distance band where spatial clustering was significant ($p < 0.01$). We used this method to examine standardized Z scores, standard deviations, and variance, as well as to identify where clustered patterns were least likely to be the result of random chance. The distance with the highest Z score was 1320 ft and 600 ft for the index surveys on 10 May and 18 May 2005, respectively. These distance bands were used in the hot-spot analysis and the output included Z scores for each steelhead observation based on the count data. Higher Z scores indicated a hot spot and lower values signified what was termed a cold spot.

RESULTS

STREAM HABITAT SURVEYS

We conducted stream habitat surveys in the Sitkoh Creek watershed during May 2005. We recorded 1,541 waypoint features to precisely map the stream network and identify significant habitat features (Table 1). We surveyed 28.7 km of stream habitat and characterized the reaches into fluvial process groups and channel types (Figure 4). This represents approximately 28% of the entire stream network identified in the watershed by the USFS. High gradient contained (HC) and moderate gradient mixed control (MM) process groups accounted for 52% of the stream network surveyed (Table 2). Additionally, 43 individual stream reaches were classified into distinct channel types and reach and summary statistics of the primary habitat characteristics are displayed in Tables 3 and 4. Seven stream reaches surveyed were not classified, representing an additional 2.1 km of stream habitat surveyed. We also mapped the distribution of several habitat features that were not included in the dataset analyzed including: confluences, ephemeral debris jams, fish observations points, waterfalls, and riparian disturbances (Appendix C1-C5).

The stream habitat survey of the mainstem of Sitkoh Creek resulted in the classification of 3 distinct fluvial process groups; flood plain (FP), moderate gradient-mixed control (MM), and low gradient-contained (LC) (see Figure 4). Immediately downstream of the lake outlet was a short section (<1 km) of FP habitat that was generally characterized by exposed gravel bars, the highest density of macro-pools and substrates ranging in size from medium gravel to sand/silt (<2 -15.9 mm). Below this reach was an LC channel, dominated by bedrock walls, with boulder-cobble-large gravel substrates (16 – 512 mm). This stream reach was followed by another short FP channel that flowed into an MM channel containing a high density of macro-pools. The lowest portion of Sitkoh Creek widened and returned to an LC channel containing the greatest density of large wood before emptying the entire Sitkoh Creek watershed into Sitkoh Bay.

We calculated the density of large and key wood accumulations, and macro-pools in 39 stream reaches and grouped the results by associated process group in Table 5 and Figure 5 and by sub-basin in Table 6. The highest density of large wood accumulation was found in MM and MC process groups and the greatest density of key wood was found in HC and AF habitats. Spatial distribution and counts of large wood (Figure 6) and key wood accumulations (Figure 7) are combined in Figure 8.

SURVEYS TO IDENTIFY SPAWNING AREAS

Reconnaissance foot surveys of the tributary streams, 10 May – 15 May (SKO35) and 18 May – 24 May 2005 (SKO45), found no adult steelhead in the tributaries. In addition, we accompanied steelhead index abundance snorkel survey crews and documented the specific locations where adult steelhead were observed in the mainstem. The collection of GPS coordinate data integrated a spatial component into the steelhead abundance index surveys and we generated several GIS maps from these surveys to begin evaluating adult steelhead distribution (Figures 9-12). Three snorkel survey teams collected data on 10 May 2005 and 1 team performed the index survey on 18 May 2005 (Table 7).

Adult steelhead density estimates were calculated for the 18 May survey and only for the first snorkel survey team on 10 May, as the potential for movement and disturbance was higher for the 2 survey teams that followed (Table 8). Density estimates were calculated for each channel type within the mainstem based on the actual length of the stream reach surveyed. These 6 stream reaches corresponded to our stream habitat survey reaches and were not intended to align with the 4 index survey reach areas used by the stock assessment crew. Mean density was calculated for the number of fish observed and does not account for parameters used to calculate final index survey abundance estimates. Furthermore, adult steelhead activity was difficult to discern during the index surveys and we do not intend to imply or infer the importance of these habitats to steelhead spawning. Overall, the density estimate for the entire mainstem was similar between the 2 surveys. However, the second index survey realized lower densities in all stream reaches with the exception of the LC2 stream reach in which steelhead density increased. In this stream reach, nearly 88% (172 of 196) of the steelhead observed were within 200m of the Sitkoh weir.

We performed 2 hot spot analyses of the steelhead observations from the abundance index surveys to detect patterns of spatial clustering. Results from the first index survey (Team 1) are displayed in Figure 13 and hot spots from the second survey are illustrated in Figure 14.

LEDP (REMOTELY-SENSED DATA)

On 26 April 2005 high-resolution, RGB digital aerial photography equipment was used to acquire imagery of the entire Sitkoh Creek watershed. Two image sets were generated from this mission. The first set contains 321 images yielding a ground resolution of 60 cm acquired from 14 flight lines flown at an altitude of 5,500 ft covering the entire watershed. The second set contains 136 images having a ground resolution of 30 cm and was acquired from 8 flight lines flown at an altitude of 3,500 ft covering the prioritized tributary streams. The 60 cm image dataset provides true color, sub-meter resolution base layer imagery that can be used to document current conditions within the watershed. The lower altitude image dataset (30 cm ground resolution) may be useful for mapping smaller features that were undetected during on-ground surveys (e.g. off-channel wetlands and ponds, disturbance areas, alluvial fans/depositional areas) or in the 60cm watershed level base layer imagery. A comparison of new LEDP imagery to previously available USFS DOQ quads shows greatly improved resolution at both 60 cm (Figures 15) and 30 cm scale resolution (Figure 16).

DISCUSSION

STREAM HABITAT SURVEYS

To better understand the relationships between stream reach characteristics and habitat features we utilized various statistical methods. In general, multiple regression and associated subset selection models did not consistently nor effectively reduce the number of variables in the model, nor did they provide meaningful biological interpretation of the data.

We evaluated the relationship between several measured stream reach and habitat characteristics and computed Pearson's product-moment correlation coefficients (ρ) to compare the association between variables as seen in the correlation matrix (Table 9). Some of the obvious relationships include positive correlations between channel bed width and bankfull width, as well as gradient and incision. Increasing counts of key wood were positively correlated with incision, and counts of large wood and macro pools. Key wood density was positively associated with gradient, large wood density and macro-pool density. Counts of macro-pools were strongly correlated with bankfull width, channel bed width, and counts of LWD (both large wood and key wood). Gradient was negatively correlated with bankfull width and channel bed width. Within each process group the relationship between these habitat features was evident (Figure 17). As the density of large wood and key wood accumulations increased so did the density of macro-pools. As well, increased density of large wood correlated with increased key wood density.

We employed canonical correlation analysis to assess the relationship between linear combinations of the set of reach characteristics (channel bed width, gradient, and incision) and linear combinations of the set of habitat characteristics (density of large wood, key wood and macro-pools, and counts of large wood, key wood and macro-pools). The test of linearity between the collection of reach (independent) and habitat (dependent) variables was significant (Wilkes'☐ = 0.26, P = 0.0007). We found that the first combination of canonical variables (R_c^2 = 0.50) showed that as channel bed width increased and gradient decreased, we observed increasing densities of large wood and higher counts of large wood and macro-pools (Figure 18). The second pair of canonical variables (R_c^2 = 0.40) explained that as gradient and incision increased, we found higher densities and counts of key wood (Figure 19). A canonical redundancy analysis showed that the combination of these 2 sets of canonical variables accounted for 80% of the variation in the reach characteristics and 48% of the variation in habitat characteristics.

FISH HABITAT RESEARCH

Research identifying relationships between stream reach characteristics and elements important to fish habitat, such as LWD and macro pools, has been widely documented in recent decades. Forest management practices, particularly logging, precipitated several studies examining the effects of experimental removals and additions of LWD on fish populations. These studies have consistently found increased winter survival and population abundance in stream reaches with larger quantities of LWD. Johnson et al. (2005) found increased freshwater survival of juvenile coho salmon *O. kisutch* and steelhead (and smolt abundance) after the input of LWD. Solazzi et al. (2000) found increased spring and summer coho populations, increased winter coho salmon survival, and increased age-1+ steelhead abundance in 2 coastal streams in Oregon where habitat was modified with additional accumulations of LWD. As well, Cederholm et al. (1997) found that after additions of LWD, winter abundance of age-0 steelhead moderately increased and juvenile coho salmon substantially increased. Bisson et al. (1988) found that steelhead and coho preferentially selected pools as rearing habitat with steelhead selecting pools with higher velocity currents than did coho. Montgomery et al. (1999) examined the influence of channel type morphology on salmonid spawning distribution and abundance. They reported that channel types appeared to explain broad patterns of salmonid abundance and distribution. In support of this concept, Bryant et al. (1991) found that channel types with greater accumulations of LWD had higher densities of fish. As we proceed in developing a habitat-based steelhead carrying capacity model, it is important to understand the documented relationships between habitat and fish populations as this will improve our ability to discern the habitat features contributing to usable fish habitat.

EFFECTS OF LARGE WOODY DEBRIS

Previous authors have investigated the role of LWD in the development of stream channel morphology (e.g., gradient, channel bed width), pool formation and sediment deposition/retention and relationships with fish distribution and abundance. LWD has been shown to form pools (Beechie and Sibley 1997; Montgomery et al. 1995), retain sediments in small (<7 m wide) streams (Bilby and Ward 1989), and provide essential elements of fish habitat, such as cover (Shirvell 1990) and refuge during high water events (Cederholm et al. 1997). Bryant (1983) discussed the effects of LWD on channel morphology and salmonid habitat in small streams, primarily the contributions of LWD to carbon input and cover.

Similar to our finding that macro-pool counts were highly correlated with large and key wood counts, Montgomery et al. (1995) found that as LWD increased there was a significant decrease in the spacing between pools (i.e., more pools). Beechie and Sibley (1997) studied streams in second-growth forests in northwestern Washington and found that LWD and pool spacing (expressed as the number of channel widths between pools) varied with channel slope (i.e., gradient) and channel width. Using multiple-regression analyses, they found that LWD was a dominant pool-forming mechanism that varied with channel slope with the strongest relationship in moderate-slope channels (2-5%). They reported that pool formation in low-slope channels, was less sensitive to LWD abundance because pools were formed by other mechanisms in these channel types when LWD abundance was low. In their study, percent gravel (proportion of the bed in patches of gravel 16-64 mm in diameter) was best explained by channel slope and channel width, and there was no significant relationship between LWD and percent gravel.

CHANNEL BED WIDTH RELATIONSHIPS

Contrary to our findings, Beechie and Sibley (1997) found no correlation between LWD density (LWD/m) and channel width, but did find a strong inverse relationship between LWD per unit area (LWD/m^2) and channel width. They also found that the mean length of LWD was positively correlated with channel width. As well, Bilby and Ward (1989) and Montgomery et al. (1995) found decreasing LWD abundance with increasing channel width. They believed that the increased mobility of smaller LWD in larger channels contributed to the decrease in LWD abundance. This difference may be an effect of the larger watershed sizes included in their study and the timber harvest associated with the streams selected. They found that stream reaches flowing through forests previously clear cut, have lower LWD loading and hence fewer pools than reaches in uncut forests. In our study, an additional analysis of LWD, macro-pools and channel bed width in relation to timber harvest could yield varying results.

EXPLORATORY DATA ANALYSIS USING MULTIVARIATE TECHNIQUES

Ecologists often employ multiple linear regression to find the best models that predict the dependent variables (Bisson et al. 1988; Bilby and Ward 1989; Beechie and Sibley 1997). In the analysis of complex datasets, the largest problem inherent with multiple regression, involves the shortcomings with variable subset selection and the potential multicollinearity between predictor variables (Mac Nally 2000). Model subset selection excludes variables for one of two reasons: 1) the variable adequately captures significant variability, or 2) another variable captures similar variability (Mac Nally 2002). The limitations of this approach as evidenced in our experience and other authors have resulted in the use of alternate modeling techniques (Imhof et al. 1996; Thompson and Lee 2000; Rosenfeld et al. 2000; Steel et al. 2004).

Canonical correlation analysis has been previously utilized by other authors to examine multivariate data (Galen and Stanton 1995; Williams et al. 2002). Our goal in assessing this dataset through multivariate techniques was to determine the cumulative contribution of several variables in order to capture the information with the least number of predictive variables in order to reduce the dimensionality of the data. In general, multiple regression did not effectively reduce the number of variables nor adequately provide meaningful biological interpretations of the data and subset selection models provided inconsistent results. Incorporation of robust statistical techniques such as canonical correlation analysis into stream habitat assessments will greatly improve our understanding of the habitat requirements of juvenile salmonids and subsequently the landscape forming processes that propagate fish habitat.

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TABLES AND FIGURES

Table 1.–Waypoint features mapped during 2005 in Sitkoh Creek watershed.

Waypoint feature	Waypoint feature code	Count
Mapping point	MAP	338
Fish observation point	FOP	281
Confluence	CON	228
Large wood accumulation	LWA	111
Stream gradient	SGD	106
Ephemerally fixed barrier, debris jam	EDJ	100
Divergence of water	DIV	54
Stream reach break	BRK	50
Riparian disturbance	RDB	45
Channel type verification	CTV	43
Side-channel attribute point	SAP	30
Road crossing	RXG	21
Begin stream survey	BSS	16
End stream survey	ESS	15
Geologically fixed barrier, waterfall	GWF	14
Human-induced barrier, other	HOT	11
Geologically fixed barrier, cascade-high gradient	GCS	11
Survey ended, reach incomplete	INC	9
Stream mouth	MOU	9
Corrugated metal pipe	CMP	7
Log stringer bridge	LSB	6
Subsurface flow	SSF	6
Removed structure	RRM	6
Bridge, undefined	BRG	4
Ground control point	CPG	4
Barrier	BRR	3
Stationary gaging instrument	GAG	1
Ephemerally fixed barrier, other	EOT	1
Point where stream exits a lake	OUT	1
Start of stream	SST	1
Top index area	TIA	1
Geologically fixed barrier, chute-high gradient	GCH	1
Permanent (long-term) bridge	PMB	1
Total waypoint features		1,541

Table 2.–Length of fluvial process groups surveyed in the Sitkoh Creek watershed, Chichagof Island, Southeast Alaska.

Fluvial process group	2005 ADF&G reach length[a] surveyed (km)	USFS length[b] (km)	USFS designated hydrography surveyed (%)
High gradient contained (HC)	7.30	76.17	10%
Moderate gradient contained (MC)	3.47	4.84	72%
Moderate gradient mixed control (MM)	7.77	8.41	92%
Alluvial fan (AF)	2.74	3.33	82%
Flood plain (FP)	3.80	2.89	100%
Palustrine (PA)	0.12	1.84	7%
Estuarine (ES)	0.16	0.06	100%
Low gradient contained (LC)	3.37	4.97	68%
Total	28.73	102.51	28%

Note: Several USFS Process Group designations were reclassified during the 2005 ADF&G survey, however percent surveyed does not reflect the new lengths of process groups.

[a] Reach length surveyed in May 2005 ADF&G *Stream Habitat Characterization Surveys* (Phase I).

[b] Stream length calculated from USFS Hydrography.

Table 3.–Individual stream reach characteristics for the Sitkoh Creek watershed, Southeast Alaska.

Basin reach	Reach CHTYP	Reach ID	Reach length (km)	Bankfull width (m)	Channel bedwidth (m)	Gradient (%)	Incision (m)	Large wood density	Key wood density	Macro -pool density
A-I	PA0	163973	0.12	1.00	0.75	1.30	1.00	60.82	17.38	69.51
A-II	MC1	164005	0.46	7.00	4.00	3.30	6.00	17.41	21.76	50.05
A-III	MC2	164034	1.40	10.00	8.00	3.00	15.00	228.99	64.20	59.92
A-IV	HC3	164179	0.23	12.00	4.00	8.90	17.00	238.75	145.90	110.53
A-V	MM1	164223	0.52	9.00	8.00	1.70	1.00	266.12	36.38	57.44
B-I	HC3	164524	0.25	14.00	7.00	9.90	25.00	233.51	173.12	132.86
B-II	HC2	164415	0.50	10.00	7.00	5.80	3.00	49.91	35.94	31.94
B-III	AF2	850021	0.23	10.50	6.00	5.20	1.00	108.02	77.78	69.13
B-IV	MMO	850019	0.19	1.20	1.00	4.70	0.75	51.75	51.75	46.58
B-V	MM1	850020	0.38	2.00	1.50	5.50	1.40	130.39	62.58	31.29
B-VI	MMO	164403	0.30	1.50	1.00	5.20	0.50	122.15	39.62	59.42
C-I	MC2	164787	1.61	13.00	10.00	2.60	20.00	218.58	34.87	60.40
C-II	MM2	164502	0.57	16.00	13.00	2.20	1.50	302.23	81.30	61.86
C-III	FP3	850018	0.51	11.00	7.00	2.20	0.75	246.10	39.38	45.28
D-I	HC4	163812	1.12	5.00	3.00	6.10	25.00	42.04	24.15	23.25
D-II	MM2	163582	3.83	12.00	7.66	1.80	1.00	208.02	53.51	31.06
D-III	HC2	163578	0.28	4.00	4.00	15.50	7.00	156.20	88.75	67.45
D-IV	FP4	164137	1.80	12.00	9.00	1.50	1.00	106.55	30.52	30.52
D-n/a	HC2	164021	0.63	6.00	3.00	8.70	1.00	14.22	7.90	53.73
E-I	HC6	164411	0.44	10.00	2.50	12.70	80.00	158.17	85.87	58.75
E-II	AF1	850016	0.24	8.00	0.00	4.40	0.00	.	.	.
F-I	HC3	164439	1.05	14.00	9.00	4.50	20.00	152.97	9.56	63.10
F-II	AF1	164611	0.66	32.00	3.00	2.30	0.50	83.71	18.26	50.23
F-III	AF1	850012	0.07	3.50	2.00	1.60	0.70	.	.	.
G-I	HC5	164831	0.29	3.50	2.00	15.80	3.00	104.39	62.63	20.88
G-II	HC0	850014	0.06	1.50	2.00	11.80	30.00	.	.	.
H-I	HC5	164702	0.19	8.00	2.00	19.70	2.00	179.67	110.97	.
I-I	AF1	164721	0.33	8.00	3.00	1.70	1.00	266.96	92.99	113.98
J-I	HC6	164889	1.44	7.00	4.00	7.70	75.00	310.72	180.44	64.79
J-II	MM1	164697	0.39	10.00	3.00	4.30	1.00	105.44	69.44	48.86
J-III	AF1	850015	0.44	10.00	3.00	2.20	0.50	120.96	68.47	70.75
J-n/a	MM1	164955	0.50	3.00	2.66	1.60	1.00	215.97	92.85	44.41
K-I	HC6	164801	0.51	2.50	2.00	11.70	15.00	167.89	65.18	75.06
K-II	AF2	164624	0.31	10.00	3.67	6.90	2.50	208.49	105.85	16.04
K-III	HC4	164666	0.32	9.00	2.00	6.80	11.00	172.52	46.21	52.37
K-IV	MM1	850017	0.20	7.00	2.00	3.30	8.00	90.76	65.55	35.29
K-V	AF1	164579	0.46	10.00	2.66	1.80	1.00	112.92	73.83	80.35
M-I	FP5	164369	0.85	27.00	21.00	1.80	1.50	186.66	46.96	97.44
M-II	LC1	164370	2.30	18.00	16.00	1.60	8.00	63.46	13.91	55.20
M-III	FP4	164324	0.64	22.00	20.00	2.00	1.00	216.04	48.53	43.83
M-IV	MM2	164252	0.89	30.50	23.00	1.40	2.50	160.24	40.62	68.83
M-V	LC2	164279	1.07	20.00	24.00	1.20	1.50	235.52	38.32	28.04
n/a	ES4	164311	0.16	22.00	12.00	1.30	1.50	.	.	.

Note: CHTYP = channel type, AF = alluvial fan, ES = estuarine, FP = flood plain, HC = high gradient contained, LC = low gradient contained. MC = moderate gradient contained, MM = moderate gradient mixed control, PA = palustrine.

Table 4.–Summary statistics of individual stream reach habitat characteristics in the Sitkoh Creek Watershed, Southeast Alaska, 2005.

Variable	n	Mean	SD	Minimum	Maximum
Bankfull width (m)	43	10.55	7.55	1.00	32.00
Channel bed width (m)	43	6.31	6.21	0.75	24.00
Gradient (%)	43	5.24	4.55	1.20	19.70
Large wood density (# x km^{-1})	39	156.80	79.02	14.22	310.72
Key wood density (# x km^{-1})	39	62.13	40.62	7.90	180.44
Macro-pool density (# x km^{-1})	38	57.38	25.54	16.04	132.86
Confluence frequency (# x km^{-1})	36	7.50	5.44	0.00	22.12
Incision depth (m)	43	9.23	17.21	0.00	80.00
Large wood counts	39	119.69	149.11	7.00	797.00
Key wood counts	39	38.92	48.80	2.00	259.00
Macro-pool counts	38	38.13	31.31	5.00	127.00

Table 5.–Stream reach habitat characteristics grouped by process group based on surveys during 2005 in the Sitkoh Creek watershed.

Process group	# reaches	Total length surveyed (km)	Large wood tallied	Key wood tallied	Macro pools tallied	Large wood density (# x km^{-1})	Key wood density (# x km^{-1})	Macro-pool density (# x km^{-1})
AF	6	2.43	339	158	160	139.38	64.96	65.78
FP	4	3.80	614	146	189	161.56	38.42	49.73
HC	13	7.24	1118	545	399	154.43	75.28	56.59
LC	2	3.37	398	73	157	118.08	21.66	46.58
MC	3	3.47	680	156	204	196.12	44.99	58.84
MM	10	7.77	1,512	438	332	194.65	56.39	42.74
PA	1	0.12	7	2	8	60.82	17.38	69.51

Note: AF = alluvial fan, FP = flood plain, HC = high gradient contained, LC = low gradient contained, MC = moderate gradient contained, MM = moderate gradient mixed control, PA = palustrine.

Table 6.–Stream reach habitat characteristics grouped by sub-basin based on surveys during 2005 in the Sitkoh Creek watershed.

Sub-basin	# reaches	Sub-basin length (km)	Mean BFW (m)	Mean CBW (m)	Mean gradient (%)	Mean incision (m)	Large wood count	Key wood count	Macro-pool count	Large wood density	Key wood density	Macro-pool density
A	5	2.73	7.80	4.95	3.64	8.00	529	154	170	194.12	56.51	62.38
B	6	1.86	6.53	3.92	6.05	5.28	205	125	104	110.20	67.19	55.90
C	3	2.68	13.33	10.00	2.33	7.42	647	122	155	241.46	45.53	57.85
D	5	7.67	7.80	5.33	6.72	7.00	1089	317	253	142.06	41.35	33.00
E	1	0.44	10.00	2.50	12.70	80.00	70	38	26	158.17	85.87	58.75
F	3	1.77	16.50	4.67	2.80	7.07	215	22	99	121.60	12.44	55.99
G	2	0.34	2.50	2.00	13.80	16.50	30	18	6	87.29	52.37	17.46
H	1	0.19	8.00	2.00	19.70	2.00	34	21	.	179.67	110.97	.
I	1	0.33	8.00	3.00	1.70	1.00	89	31	38	266.96	92.99	113.98
J	4	2.76	7.50	3.17	3.95	19.38	647	362	165	234.61	131.26	59.83
K	5	1.80	7.70	2.47	6.10	7.50	276	128	104	153.21	71.05	57.73
M	5	5.75	23.50	20.80	1.60	2.90	837	180	329	145.63	31.32	57.24

Note: BFW = bankfull width, CBW = channel bed width.

Table 7.–Steelhead abundance index surveys at Sitkoh Creek, Chichagof Island, Southeast Alaska.

Index survey	Channel type	Steelhead count Team 1	Steelhead count Team 2	Steelhead count Team 3
SKO35	FP5	9	9	6
SKO35	LC1	39	37	28
SKO35	FP4	15	18	7
SKO35	MM2	38	34	29
SKO35	LC2	138	158	73
SKO35	ES4	16	13	5
Total		255	269	148
SKO45	FP5	8		
SKO45	LC1	10		
SKO45	FP4	11		
SKO45	MM2	23		
SKO45	LC2	196		
SKO45	ES4	0		
Total		248	n/a	n/a

Note: SKO35 conducted on 5/10/05 and SKO45 on 5/18/05. ES = estuarine, FP = flood plain, LC = low gradient contained, MM = moderate gradient mixed control.

Table 8.–Mean adult steelhead density within each stream reach channel type for the Sitkoh Creek watershed, Southeast Alaska.

Index survey	Channel type	Team 1 steelhead count (n)	Distance snorkeled (km)	Team 1 adult steelhead density (# x km^{-1})
SKO35	FP5	9	0.85	10.59
SKO35	LC1	39	1.25	31.13
SKO35	FP4	15	0.64	23.44
SKO35	MM2	38	0.89	42.70
SKO35	LC2	138	1.07	128.97
SKO35	ES4	16	0.06	275.86
Total		255	4.76	53.56
SKO45	FP5	8	0.85	9.41
SKO45	LC1	10	1.25	7.98
SKO45	FP4	11	0.64	17.19
SKO45	MM2	23	0.89	25.84
SKO45	LC2	196	1.07	183.18
SKO45	ES4	0	0.06	0.00
Total		248	4.76	52.09

Note: ES = estuarine, FP = flood plain, LC = low gradient contained, MM = moderate gradient mixed control.

Table 9.–Pearson correlation matrix of individual stream reach and habitat characteristics as observed during 2005 for the Sitkoh Creek watershed, Southeast Alaska.

	Reach length	Bankfull width	Channel bed width	Gradient	Large wood density	Key wood density	Macro-pool density	Confluence frequency	Incision depth	Large wood counts	Key wood counts	Macro-pool counts
Reach length (ρ)	1	0.26539	0.37158	-0.29654	0.11642	-0.21215	-0.23294	-0.07898	0.09658	0.86795	0.65728	0.85208
(p)		0.0854	0.0142	0.0535	0.4803	0.1948	0.1593	0.647	0.5378	<.0001	<.0001	<.0001
(n)	43	43	43	43	39	39	38	36	43	39	39	38
Bankfull width (ρ)	0.26539	1	0.76489	-0.38544	0.19367	-0.15469	0.15311	0.04478	-0.11344	0.21394	0.03593	0.39294
(p)	0.0854		<.0001	0.0107	0.2375	0.3471	0.3587	0.7954	0.4689	0.191	0.8281	0.0147
(n)	43	43	43	43	39	39	38	36	43	39	39	38
Channel bed width (ρ)	0.37158	0.76489	1	-0.40493	0.29512	-0.21733	0.03317	-0.01666	-0.13349	0.33551	0.09384	0.45547
(p)	0.0142	<.0001		0.0071	0.0682	0.1838	0.8433	0.9232	0.3935	0.0368	0.5699	0.0041
(n)	43	43	43	43	39	39	38	36	43	39	39	38
Gradient (ρ)	-0.29654	-0.38544	-0.40493	1	-0.04373	0.42564	0.05929	-0.00487	0.36732	-0.27158	-0.06196	-0.30127
(p)	0.0535	0.0107	0.0071		0.7915	0.0069	0.7236	0.9775	0.0154	0.0944	0.7079	0.066
(n)	43	43	43	43	39	39	38	36	43	39	39	38
Large wood density(ρ)	0.11642	0.19367	0.29512	-0.04373	1	0.56394	0.31787	-0.20395	0.23603	0.48439	0.4743	0.25424
(p)	0.4803	0.2375	0.0682	0.7915		0.0002	0.0518	0.2328	0.148	0.0018	0.0023	0.1235
(n)	39	39	39	39	39	39	38	36	39	39	39	38
Key wood density (ρ)	-0.21215	-0.15469	-0.21733	0.42564	0.56394	1	0.45996	-0.14345	0.4348	0.07596	0.43353	-0.06204
(p)	0.1948	0.3471	0.1838	0.0069	0.0002		0.0037	0.4039	0.0057	0.6458	0.0058	0.7114
(n)	39	39	39	39	39	39	38	36	39	39	39	38
Macro-pool density(ρ)	-0.23294	0.15311	0.03317	0.05929	0.31787	0.45996	1	-0.05113	0.15348	-0.11263	-0.01346	0.15012
(p)	0.1593	0.3587	0.8433	0.7236	0.0518	0.0037		0.7671	0.3576	0.5008	0.9361	0.3683
(n)	38	38	38	38	38	38	38	36	38	38	38	38
Confluence frequency (ρ)	-0.07898	0.04478	-0.01666	-0.00487	-0.20395	-0.14345	-0.05113	1	-0.20536	-0.12865	-0.15875	-0.09215
(p)	0.647	0.7954	0.9232	0.9775	0.2328	0.4039	0.7671		0.2295	0.4546	0.3551	0.593
(n)	36	36	36	36	36	36	36	36	36	36	36	36

-continued-

Table 9.–Page 2 of 2.

		Reach length	Bankfull width	Channel bed width	Gradient	Large wood density	Key wood density	Macro-pool density	Confluence frequency	Incision depth	Large wood counts	Key wood counts	Macro-pool counts
Incision	(ρ)	0.09658	-0.11344	-0.13349	0.36732	0.23603	0.4348	0.15348	-0.20536	1	0.21015	0.47658	0.22675
	(p)	0.5378	0.4689	0.3935	0.0154	0.148	0.0057	0.3576	0.2295		0.1991	0.0022	0.171
	(n)	43	43	43	43	39	39	38	36	43	39	39	38
Large wood counts	(ρ)	0.86795	0.21394	0.33551	-0.27158	0.48439	0.07596	-0.11263	-0.12865	0.21015	1	0.84569	0.7641
	(p)	<.0001	0.191	0.0368	0.0944	0.0018	0.6458	0.5008	0.4546	0.1991		<.0001	<.0001
	(n)	39	39	39	39	39	39	38	36	39	39	39	38
Key wood counts	(ρ)	0.65728	0.03593	0.09384	-0.06196	0.4743	0.43353	-0.01346	-0.15875	0.47658	0.84569	1	0.62164
	(p)	<.0001	0.8281	0.5699	0.7079	0.0023	0.0058	0.9361	0.3551	0.0022	<.0001		<.0001
	(n)	39	39	39	39	39	39	38	36	39	39	39	38
Macro-pool counts	(ρ)	0.85208	0.39294	0.45547	-0.30127	0.25424	-0.06204	0.15012	-0.09215	0.22675	0.7641	0.62164	1
	(p)	<.0001	0.0147	0.0041	0.066	0.1235	0.7114	0.3683	0.593	0.171	<.0001	<.0001	
	(n)	38	38	38	38	38	38	38	36	38	38	38	38

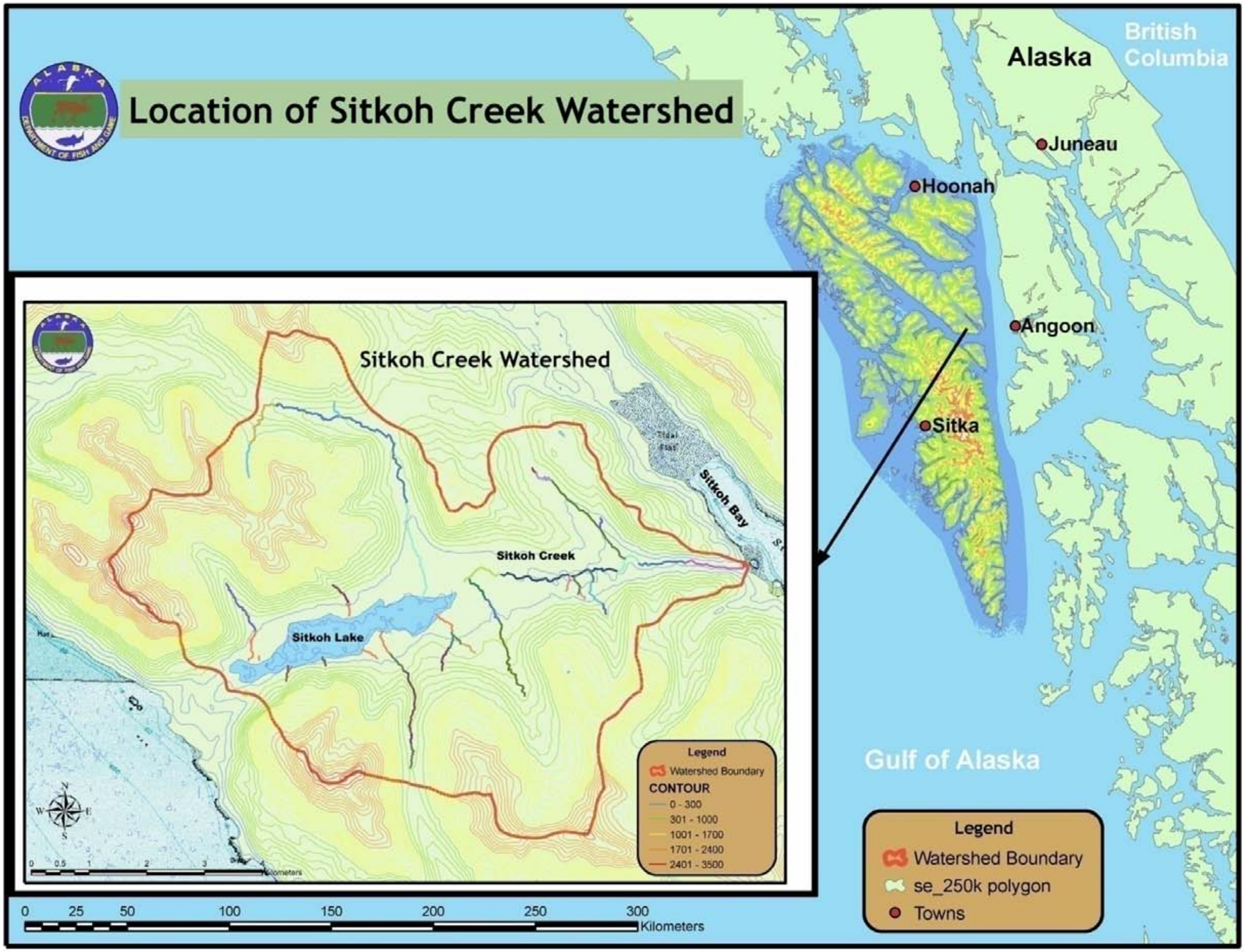


Figure 1.–Location of Sitkoh Creek watershed on Chichagof Island in Southeast Alaska.

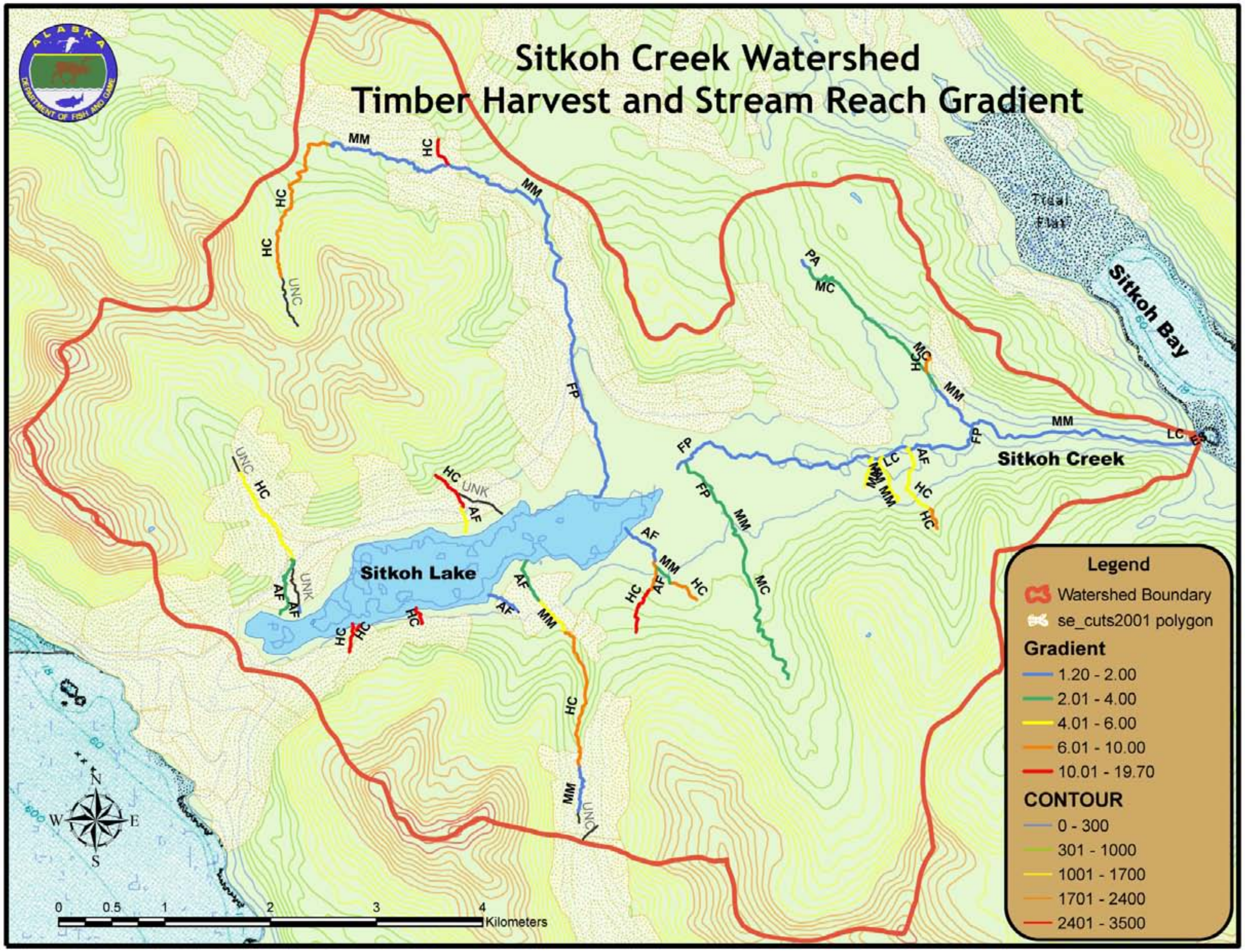


Figure 2.–Map showing Sitkoh Creek watershed timber harvests and stream reach gradient.

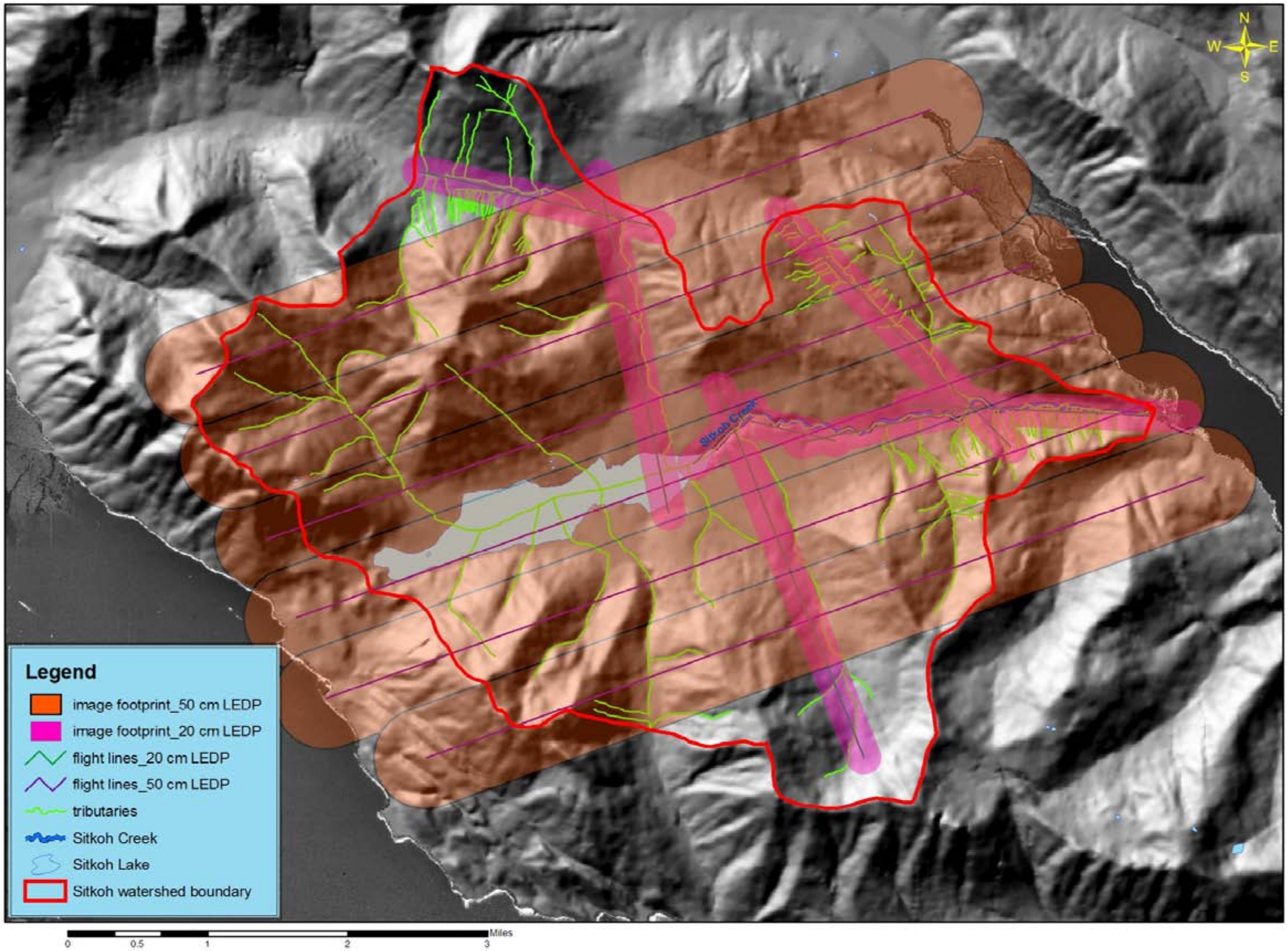


Figure 3.–Low elevation digital photography (LEDP) image footprints and flight lines delineated for imagery acquisition.

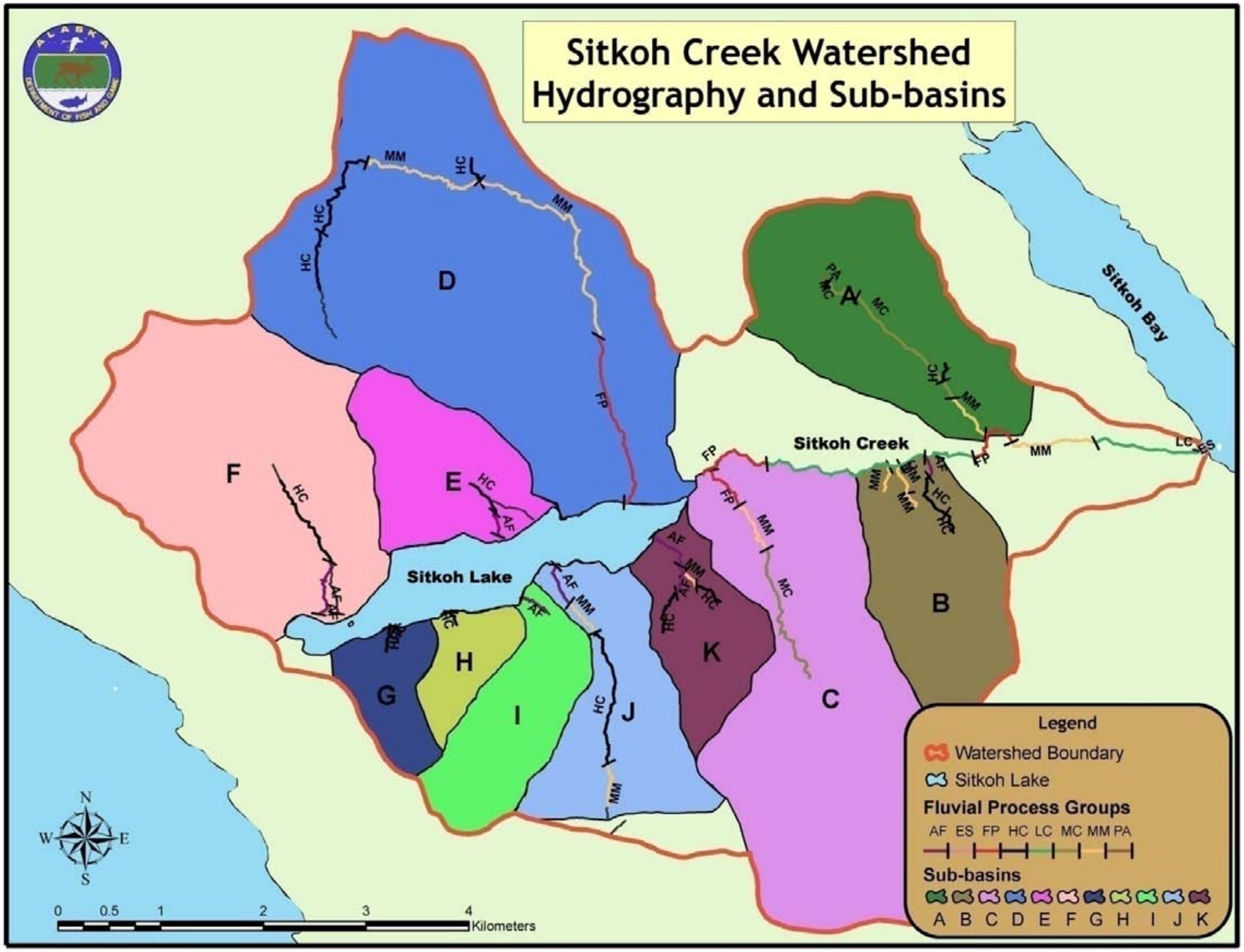


Figure 4.–Map showing predominate hydrography and sub-basins within the Sitkoh Creek watershed on Chichagof Island, Southeast Alaska based on surveys in May 2005. AF =alluvial fan, ES = estuarine, FP = flood plain, HC= high gradient contained, LC = large contained, MC = moderate gradient contained, MM = moderate gradient mixed control, PA = palustrine.

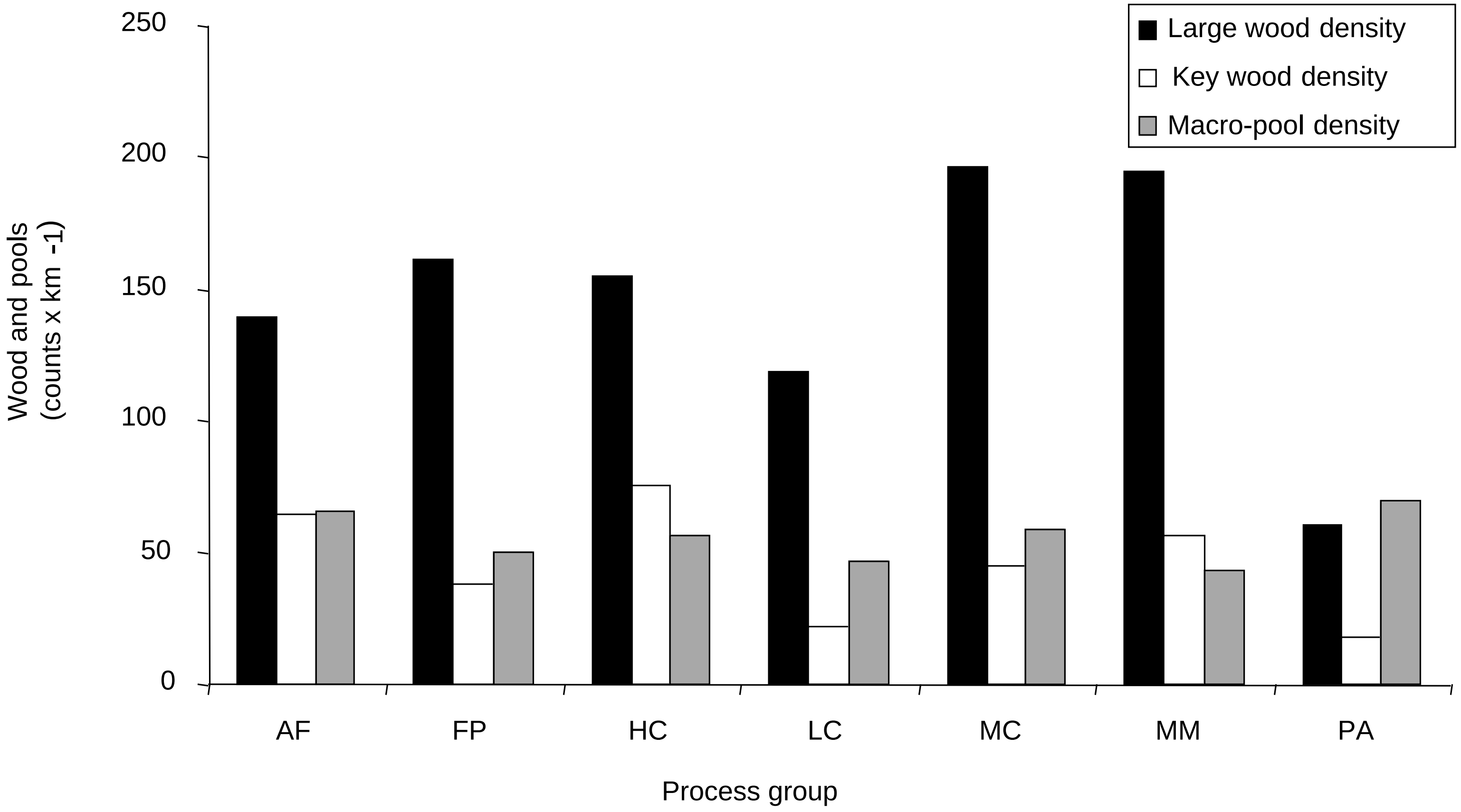


Figure 5.–Densities of large wood, key wood accumulations, and macro-pools grouped by fluvial process group in the Sitkoh Creek Watershed. AF =alluvial fan, FP = flood plain, HC= high gradient contained, LC = large contained, MC = moderate gradient contained, MM = moderate gradient mixed control, PA = palustrine.

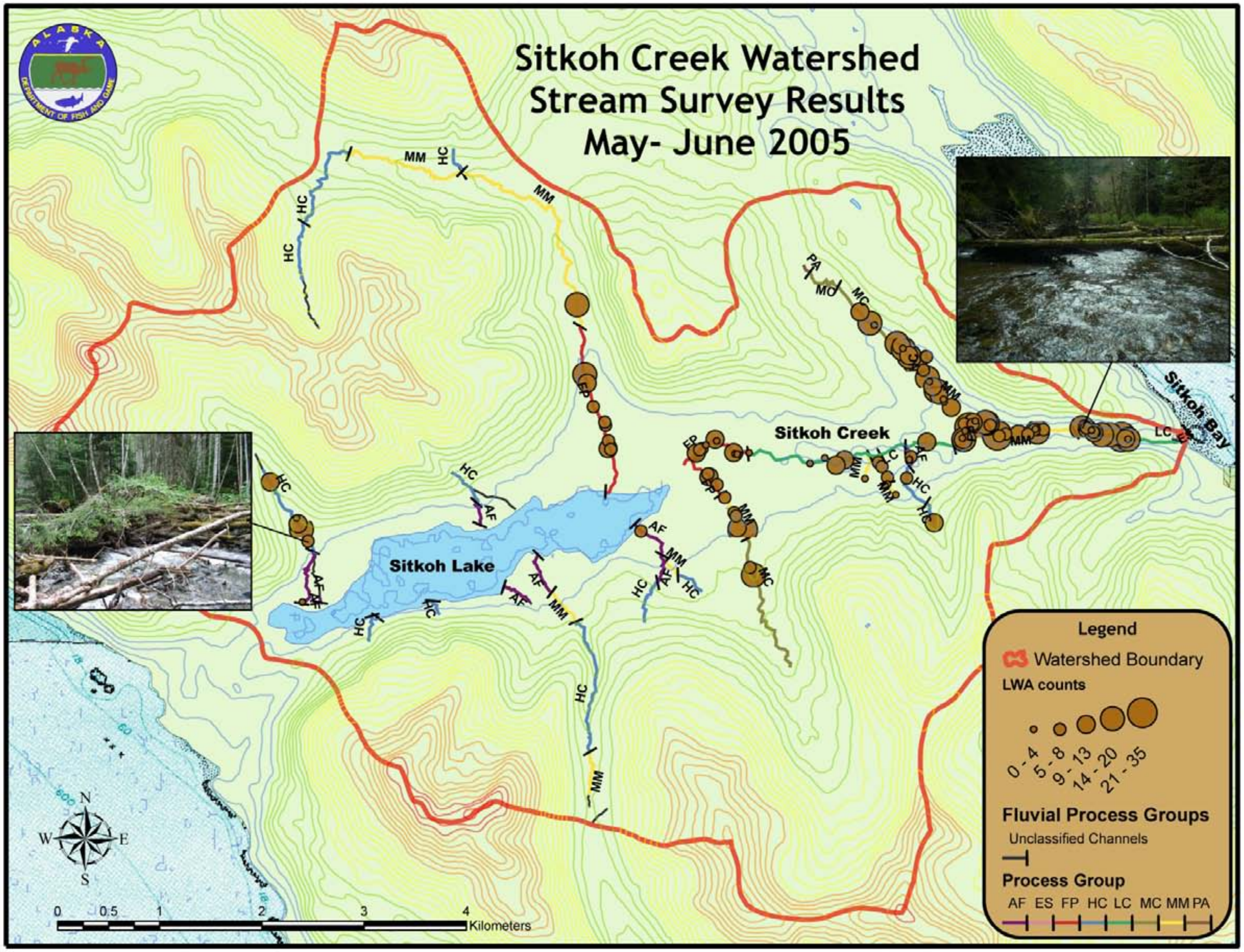


Figure 6.–Locations and associated counts of large wood accumulations in the Sitkoh Creek watershed.

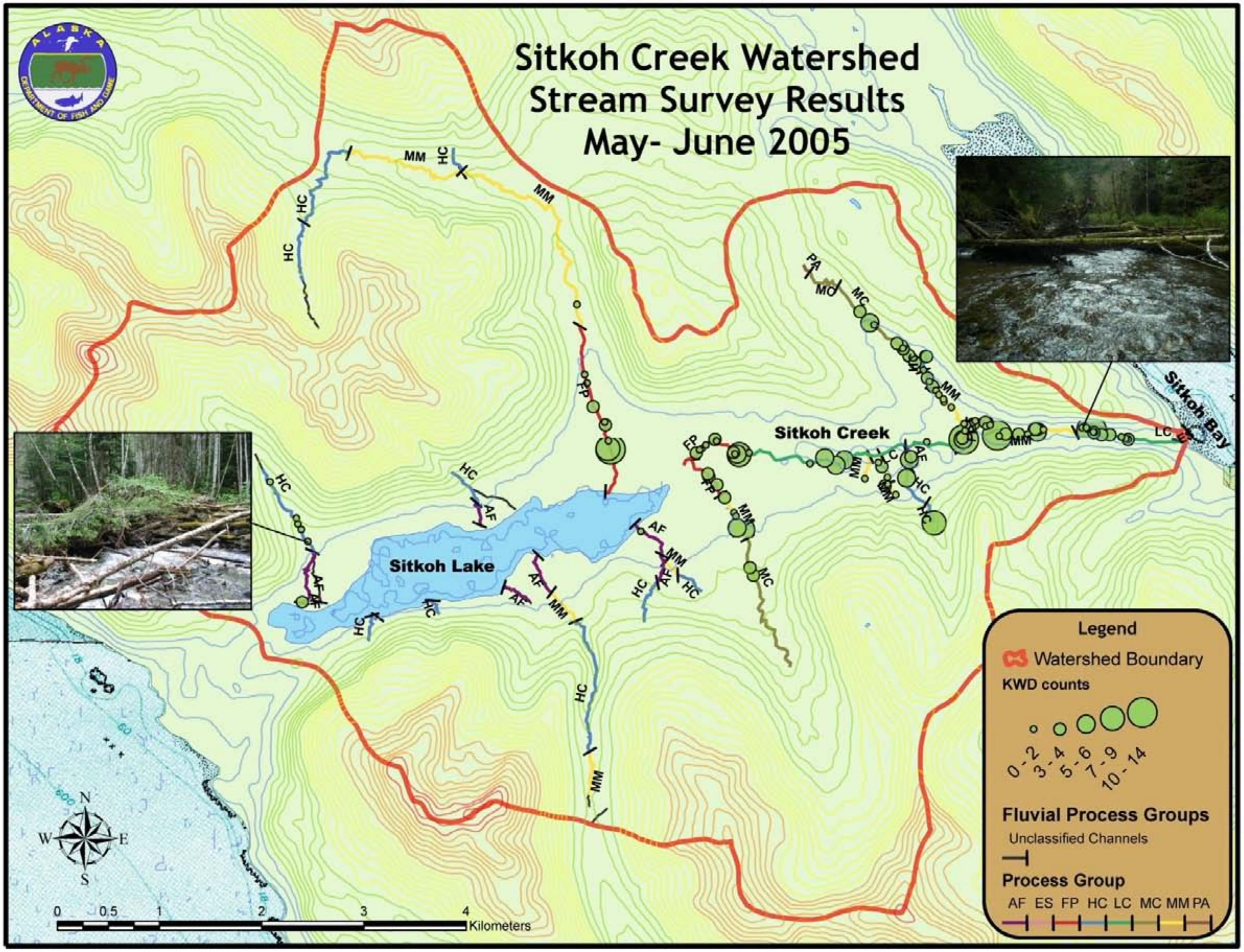


Figure 7.–Locations and associated counts of key wood in the Sitkoh Creek watershed.

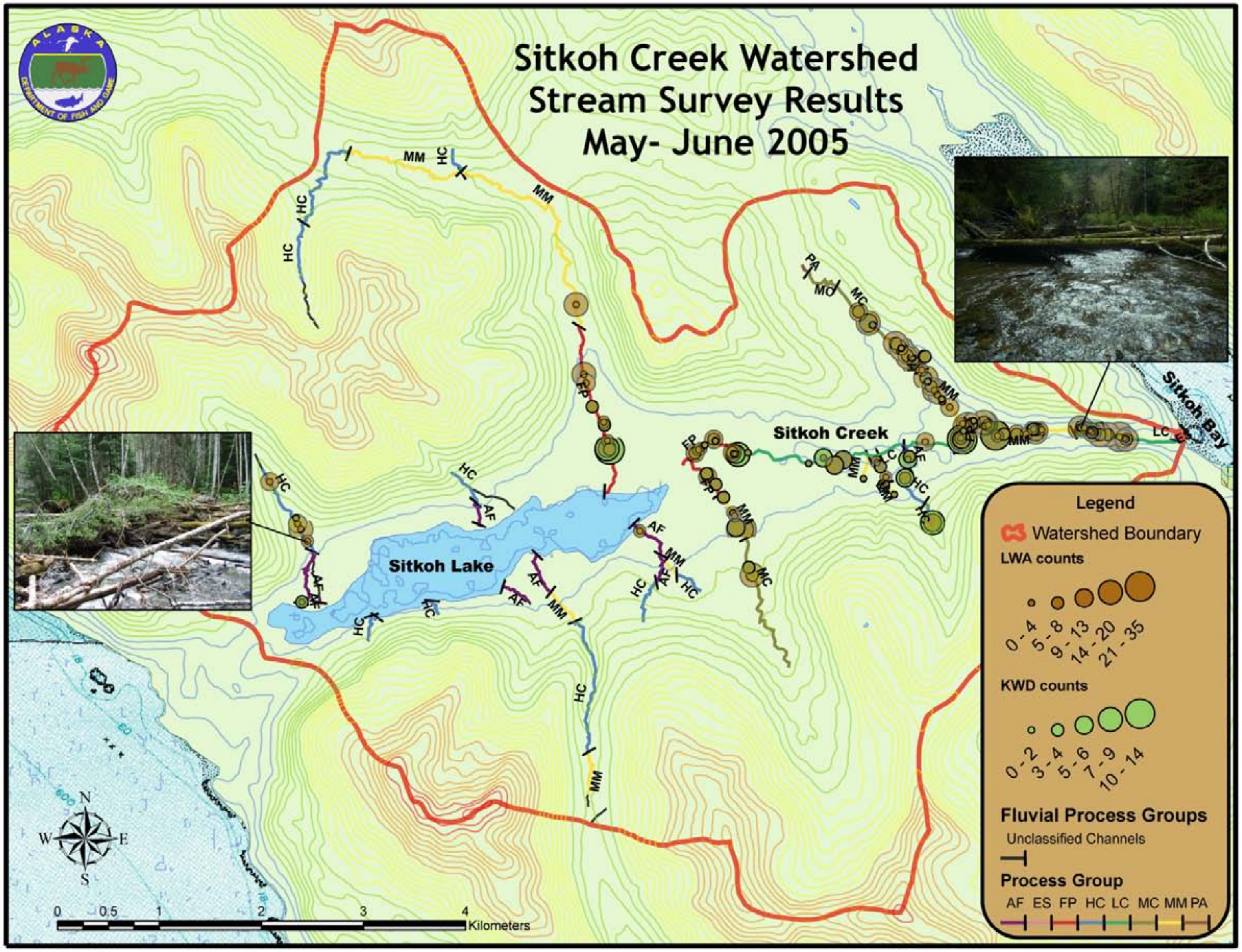


Figure 8.–Locations and counts of large wood and key wood combined in the Sitkoh Creek watershed.

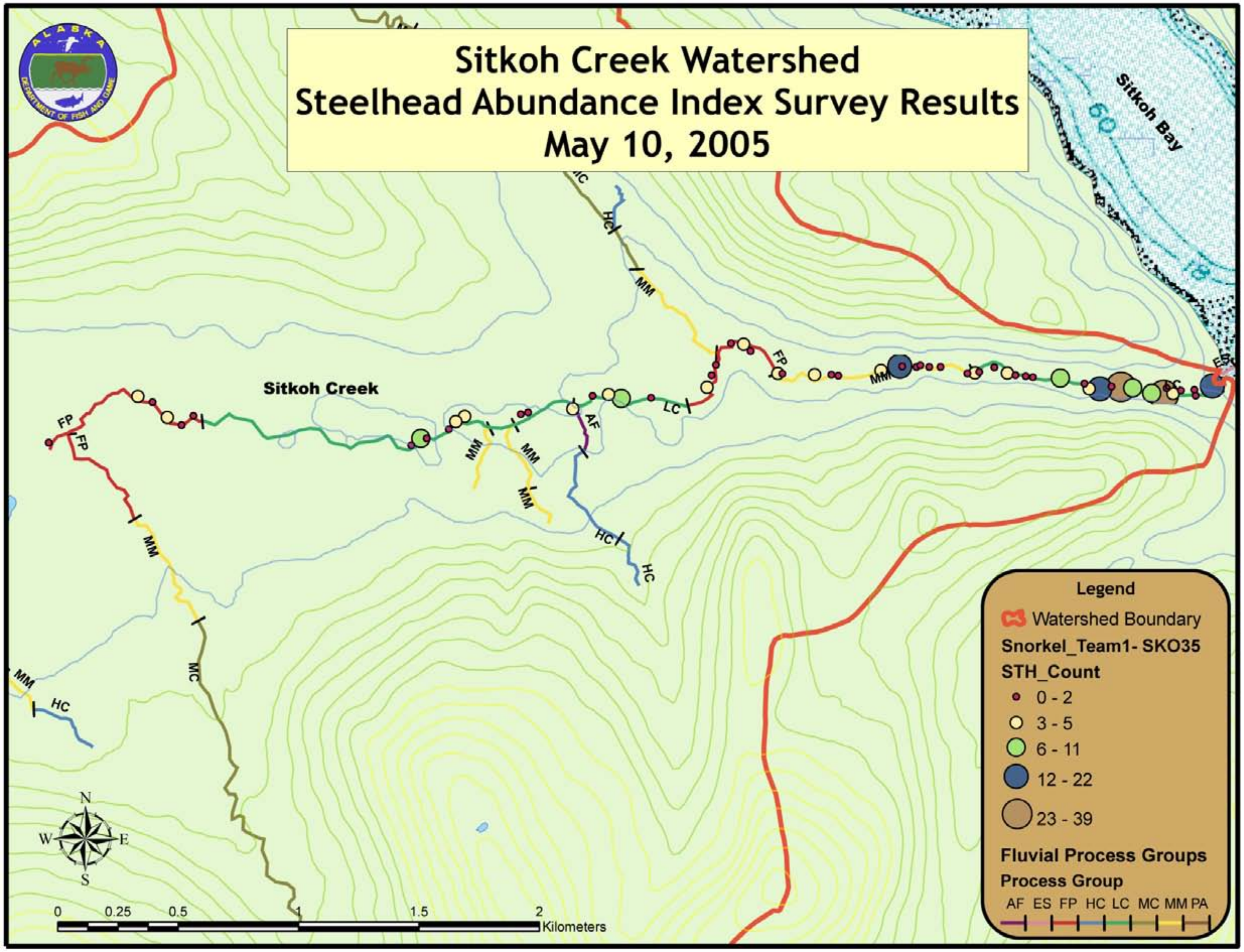


Figure 9.–Steelhead observations (Team 1) during the abundance index survey of Sitkoh Creek on May 10, 2005.

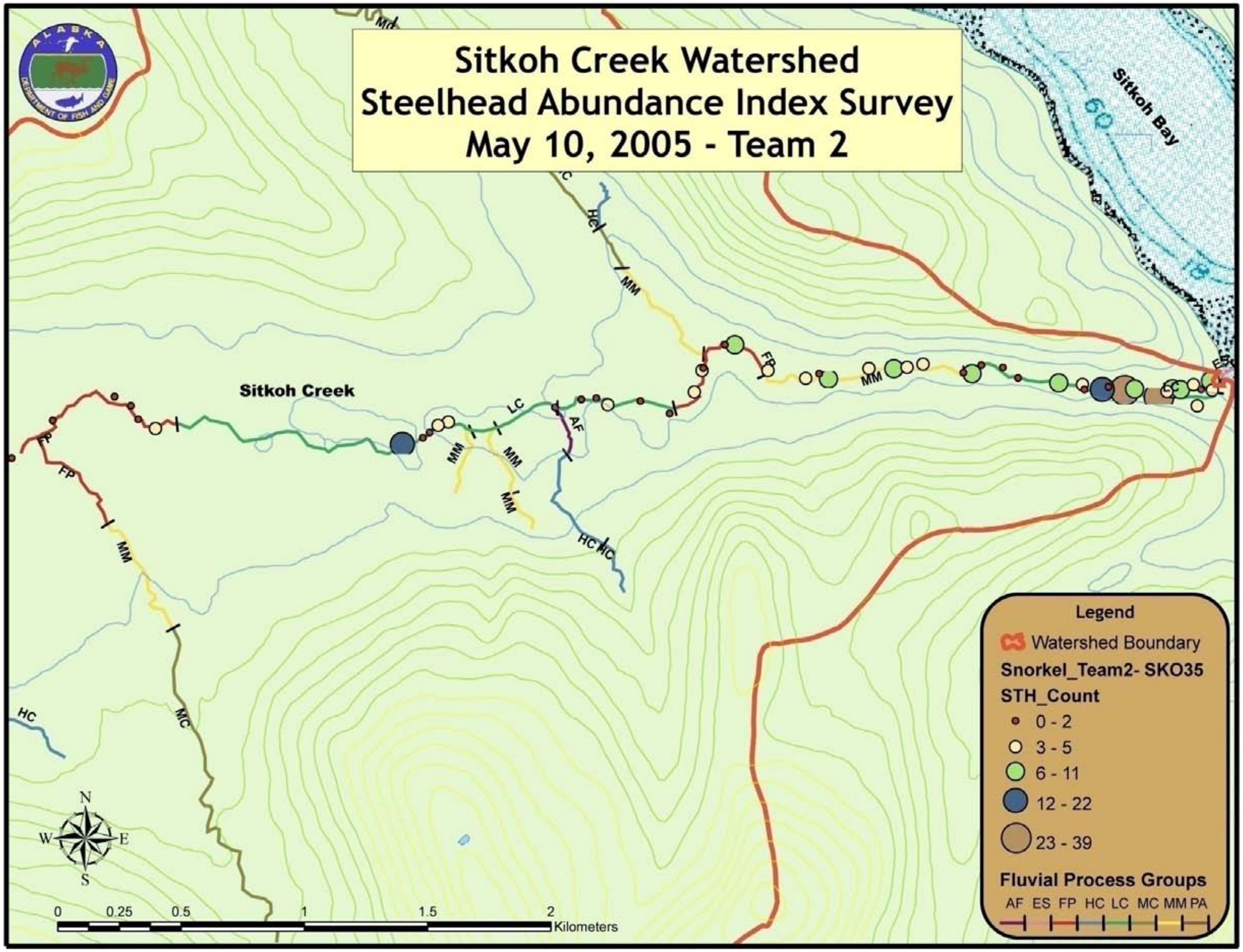


Figure 10.–Steelhead observations (Team 2) during the abundance index survey of Sitkoh Creek on May 10, 2005.

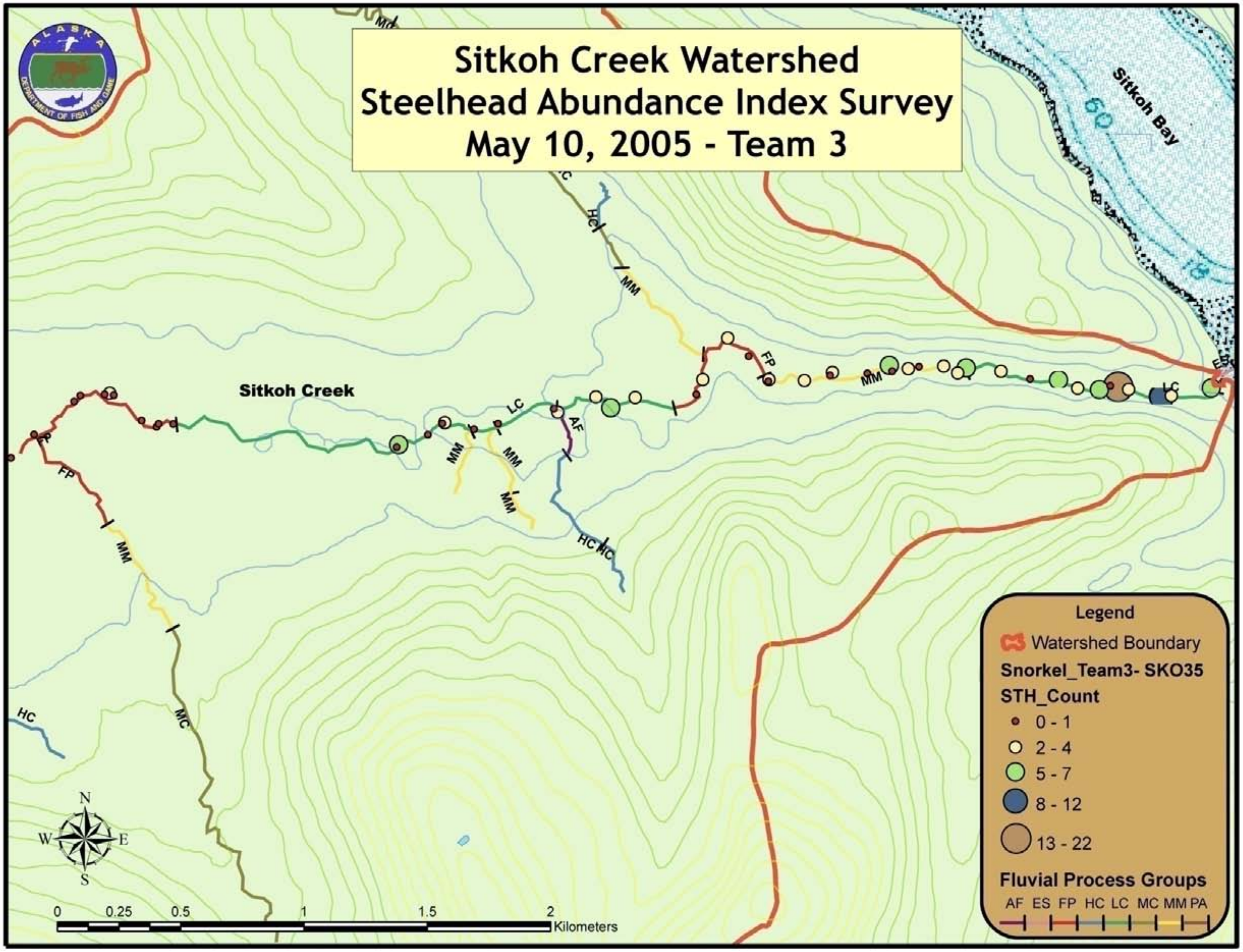


Figure 11.–Steelhead observations (Team 3) during the abundance index survey of Sitkoh Creek on May 10, 2005.

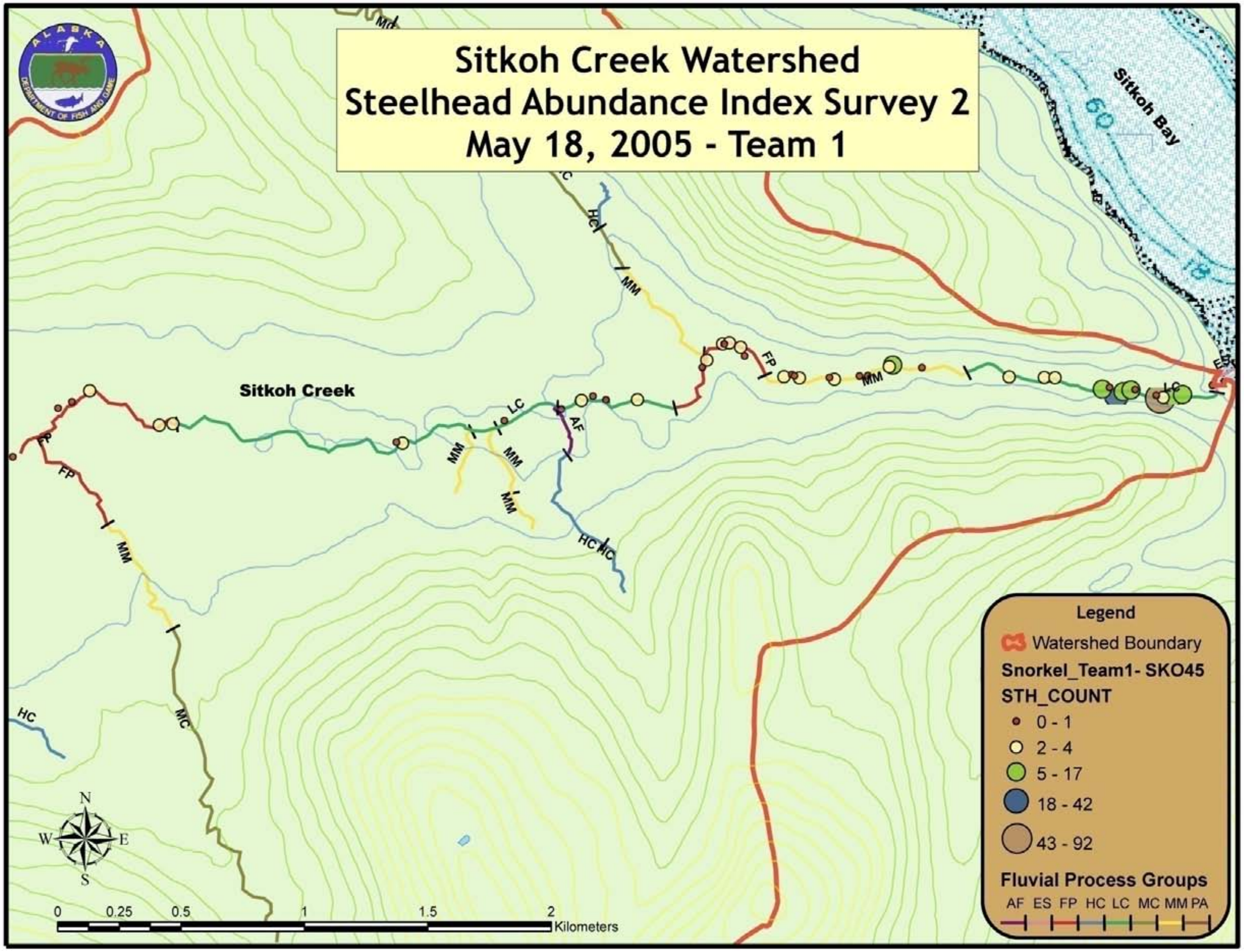


Figure 12.–Steelhead observations during the second abundance index survey of Sitkoh Creek on May 18, 2005.

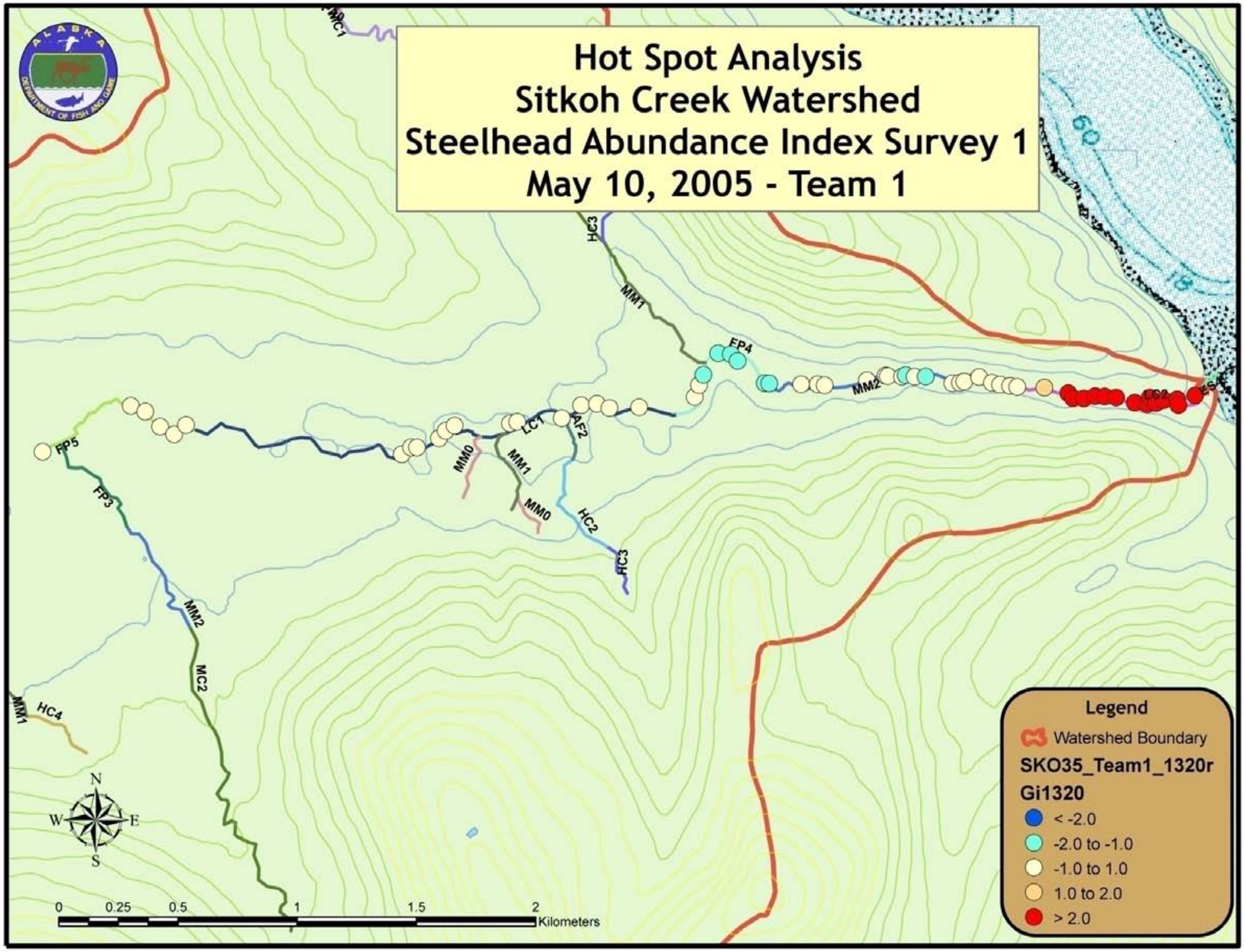


Figure 13.–Hot spot analysis of steelhead observations (Team 1) during the abundance index survey of Sitkoh Creek on May 10, 2005.

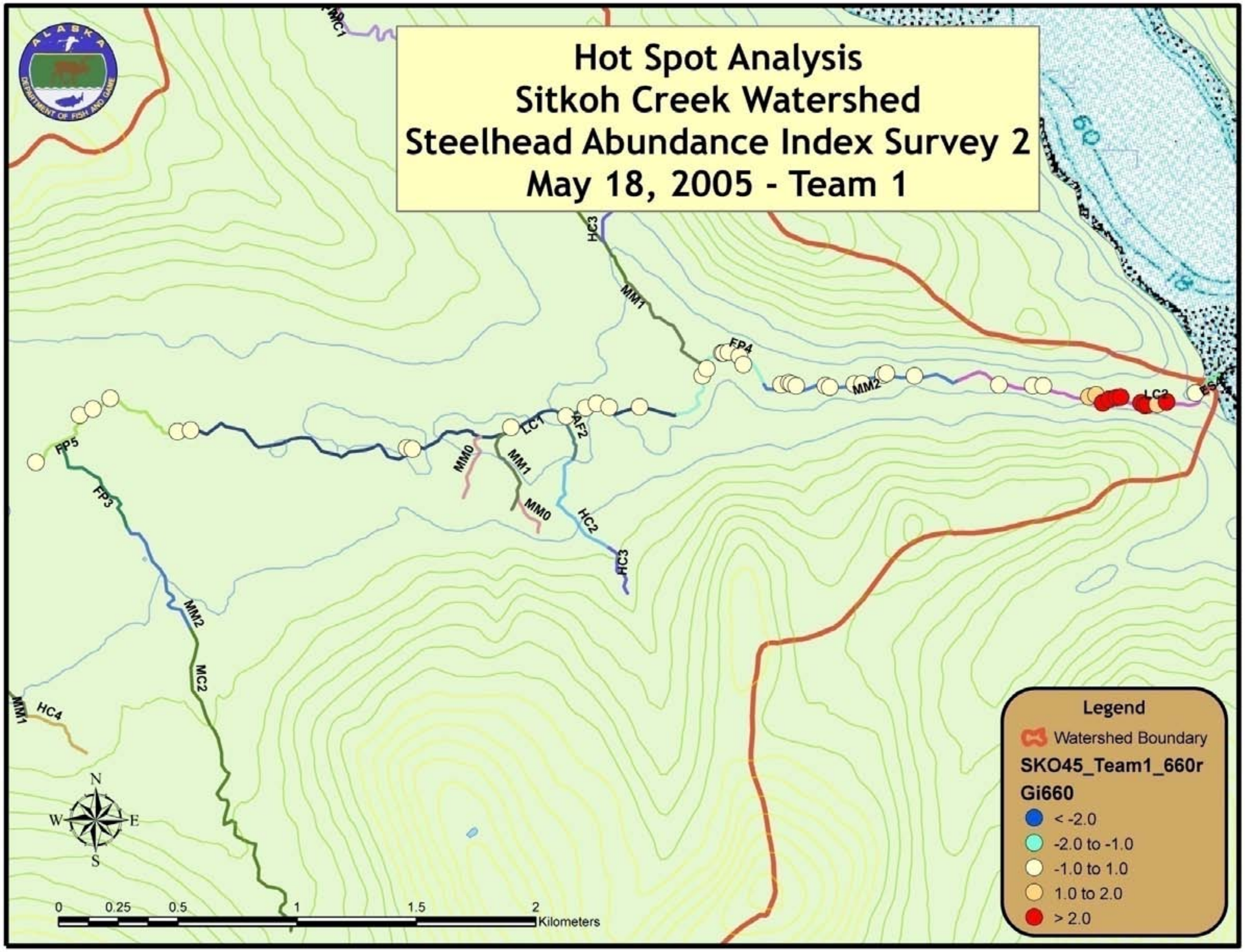


Figure 14.–Hot spot analysis of steelhead observations during the abundance index survey of Sitkoh Creek on May 18, 2005.

Figure 15.–Comparison of 60cm LEDP to DOQ 2 meter resolution.

Figure 16.–Comparison of 30cm LEDP to DOQ 2 meter resolution.

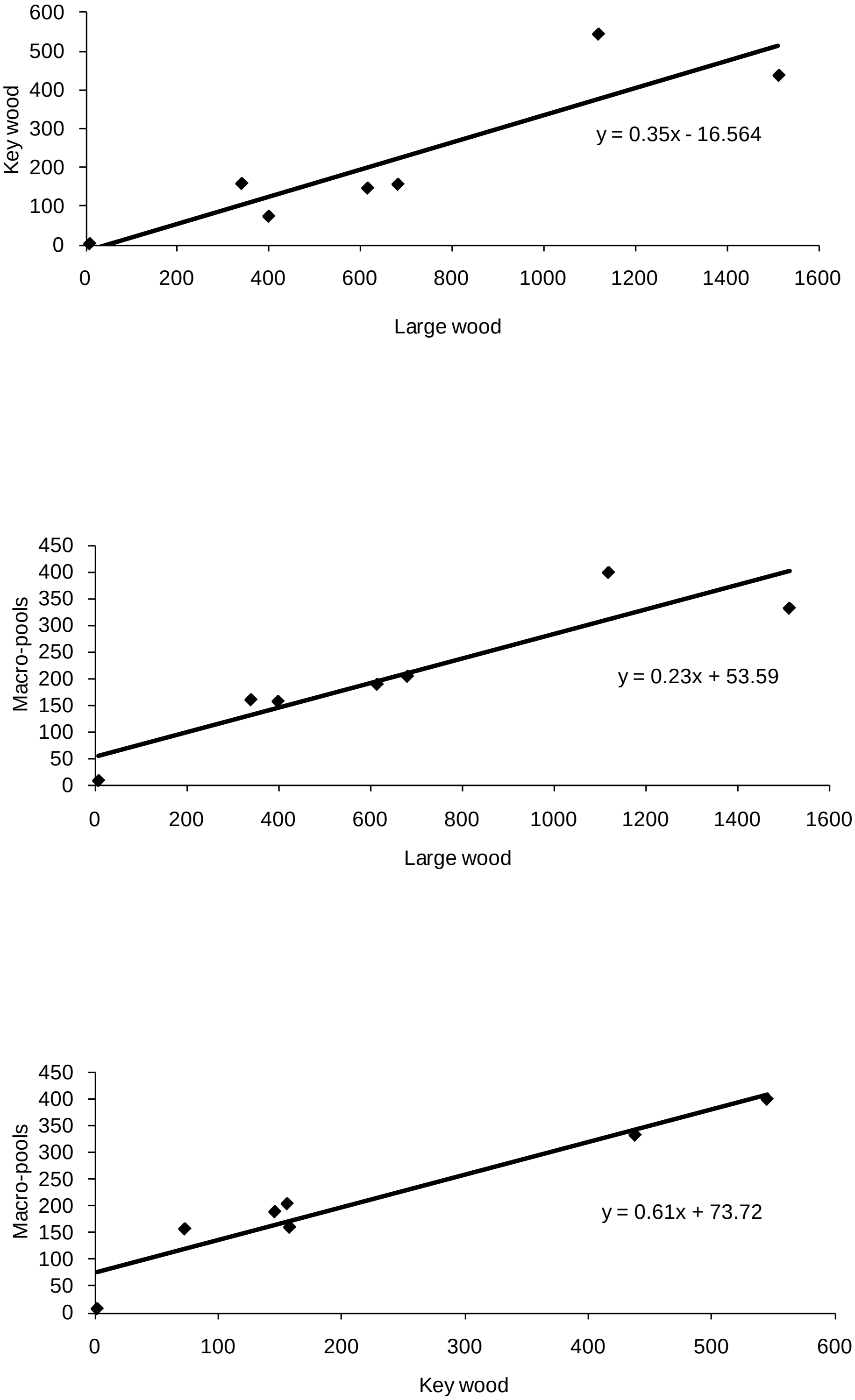


Figure 17.–Relationship between large wood, key wood and macro-pools grouped by fluvial process group.

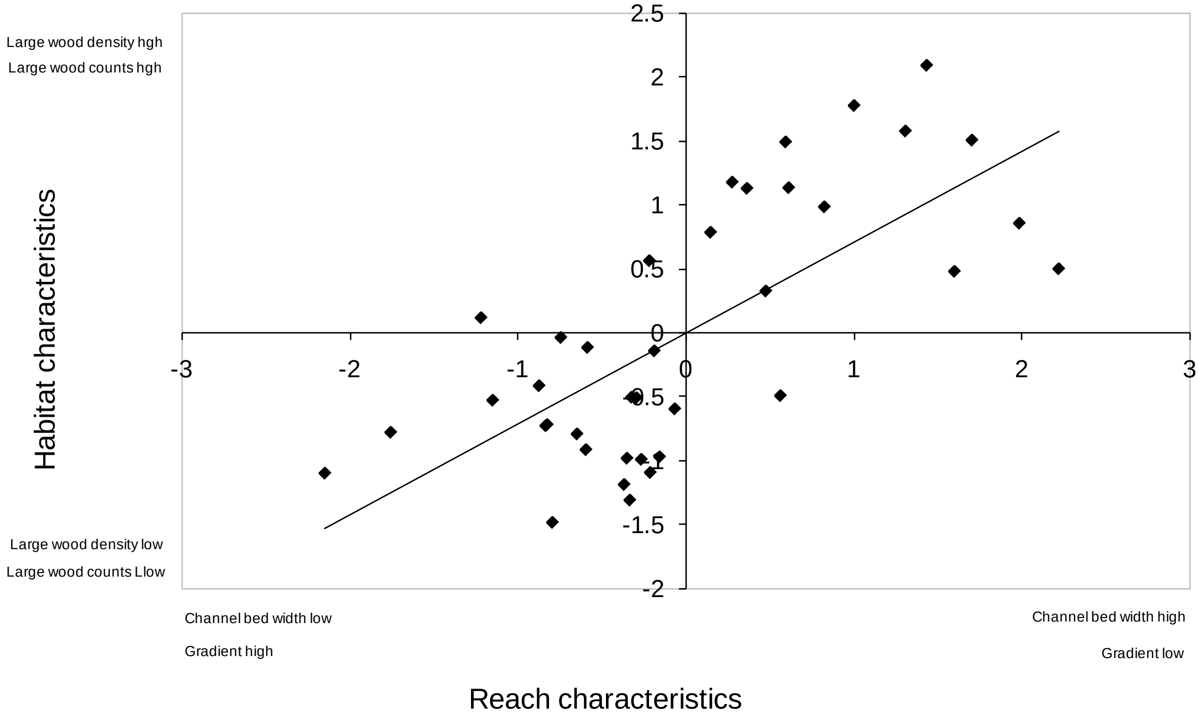


Figure 18.–Canonical correlation analysis identifying the relationships between the first combination of reach characteristics and habitat characteristics (y = 0.7098 x -2E-16).

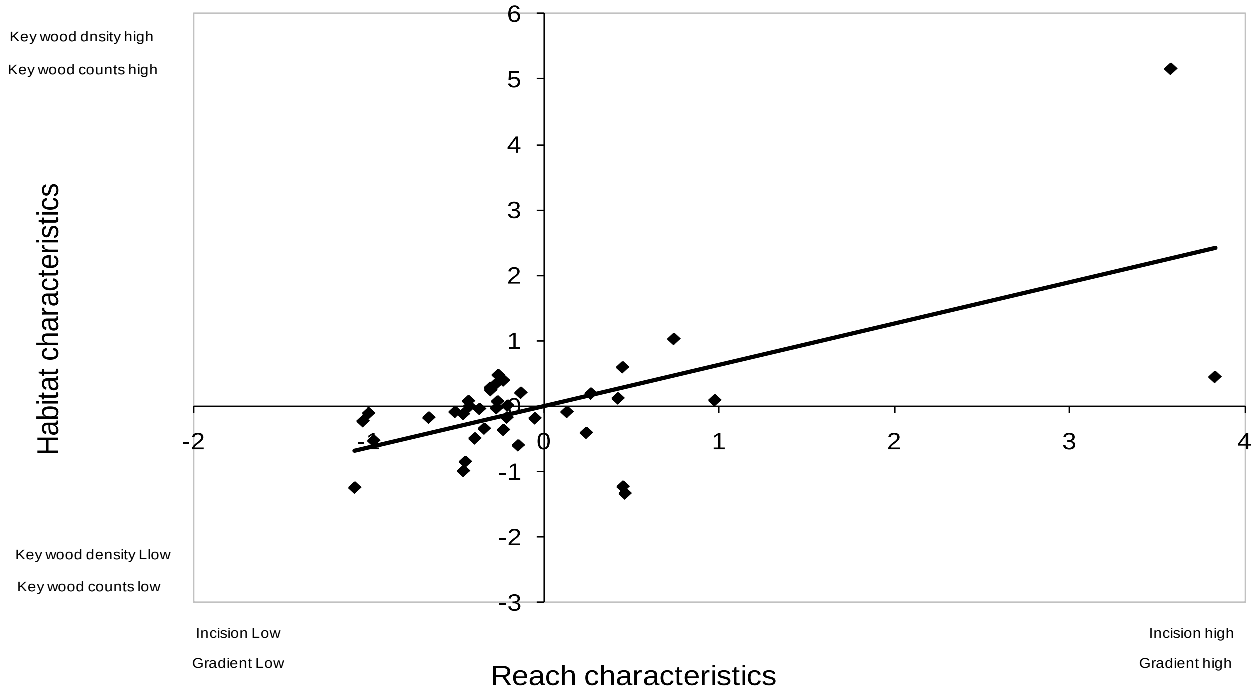


Figure 19.–Canonical correlation analysis identifying the relationships between the second combination of reach characteristics and habitat characteristics (y = 0.6322 x -1E-17).

APPENDIX A

Appendix A1.–Summary statistics for Sitkoh watershed, Chichagof Island, Southeast Alaska.

Reorting metric	Statistics and (units)	Comments/description
Watershed code	1901020307170000	6th level hydrological unit code (HUC)
USGS quads	Sitka – C4, C3, B4, B3	USGS quad maps covered in watershed
Watershed area	4,972.95 (ha)	Area of watershed at 6th level HUC
Predominant ecological subsection	IIB1f – 3,826.61 (ha)	11B1f – Peril Strait Granatics
Next dominant ecological subsection	IIB2c – 1,146.34 (ha)	IIB2c – Kook Lake Carbonates
Predominant landowner	USFS – 4,968.68 (ha)	Federal ownership
Road length in watershed	30.19 (km)	Unimproved
Elevation ≤ to 152 m	1,691.33 (ha) = 34% of total	Number (ha) and % of total area in watershed ≤ 152 m elevation
Slope ≤ to 2%	1,453.22 (ha) = 29% of total	Number (ha) and % of total area in watershed ≤ 2 % slope
Mean elevation	921 (m)	Mean elevation (m) throughout watershed
Stream length – HC	76.17 (km)	High-gradient contained (HC)
Stream length – MC	4.84 (km)	Moderate gradient contained (MC)
Stream length – MM	8.41 (km)	Moderate gradient mixed control (MM)
Stream length – AF	3.33 (km)	Alluvial fan (AF)
Stream length – FP	2.89 (km)	Flood plain (FP)
Stream length – PA	1.84 (km)	Palustrine (PA)
Stream length – ES	0.06 (km)	Estuarine (ES)
Stream length – LC	4.97 (km)	low gradient contained (LC)
Lakes ≥ 0.4 ha	2	Number of lakes in watershed ≥ 0.4 ha (1 acre)
Anadromous lakes	1	Number of lakes in watershed with anadromous species present
Lake surface area	200.40 (ha)	Total surface area (ha) of all lakes in watershed
Anadromous lake surface area	200.40 (ha)	Total surface area (ha) of anadromous lakes in watershed
Timber harvest area	919.19 (ha)	Total area (ha) of timber harvest in watershed

APPENDIX B

Appendix B1.–Stream habitat survey method detailing physical and biological features.

At a representative section of each stream reach, termed a Channel Type Verification (CTV) point, pertinent habitat features necessary for characterizing channel-type were recorded. To classify the stream reach according to fluvial process group and channel type, we recorded stream gradients, channel bed widths, incision depth, bankfull width, bank composition, channel pattern, dominant substrates, and surrounding riparian vegetation types. Stream gradient measurements were taken at the extents of the reach, as well as at the CTV point, and the mean gradient ($\bar{g}$) for reach *i* was calculated as:

$$\bar{g} = \frac{\sum g_i}{n} \tag{1}$$

where:

g_i = individual gradient measures taken within reach *i*; and

n = number of measures taken within reach *i*.

Incision depth, to the nearest 0.5 m, was measured as the vertical distance (m) between the first major slope break above bankfull stage and the channel bottom at the thalweg. Bankfull width was measured from the lateral extent of the water surface at bankfull depth, where bankfull depth is the water surface elevation required to completely fill the channel to a point above which water would spill onto the floodplain. Bankfull width, similar to channel bed width, is also independent of the current flow regime, although past high-flow events ultimately control the extent of this parameter and its effect on the floodplain. Bank composition refers to the dominant geologic material composing the stream bank. Channel pattern indicates the connectivity of the mainstream channel, i.e., single or multiple. We visually identified and measured the 3 most dominant substrate size classes, with the exception of bedrock. Distance of the stream reach was calculated using ArcGIS extension X Tools Pro (Version 2.0.0) based on the waypoints attributed to the top and bottom stream reach break (BRK) points. Side channels and disturbance feature lengths were measured in the field using a hand-held laser range finder.

When surveyors encountered accumulations of woody debris, the number of pieces of large wood and key wood were counted. Large wood is defined simply as all pieces of wood (including rootwads) within the bankfull width that are greater than 10 cm diameter, and longer than 1 m in length. Wood pieces that were large relative to the channel size and appeared to contribute to important geomorphic functions (including the formation of pools and cover) are termed key pieces. The qualifying dimensions of key pieces are scaled to the average channel bed width (Table B1). The density of large wood and key wood were calculated similarly using Equation 3.

Large wood density (D_i) for each reach was calculated as:

$$D_i = \frac{\sum w_i}{l_i} \tag{2}$$

where:

w_i = number of large (or key) wood pieces counted in reach *i*; and

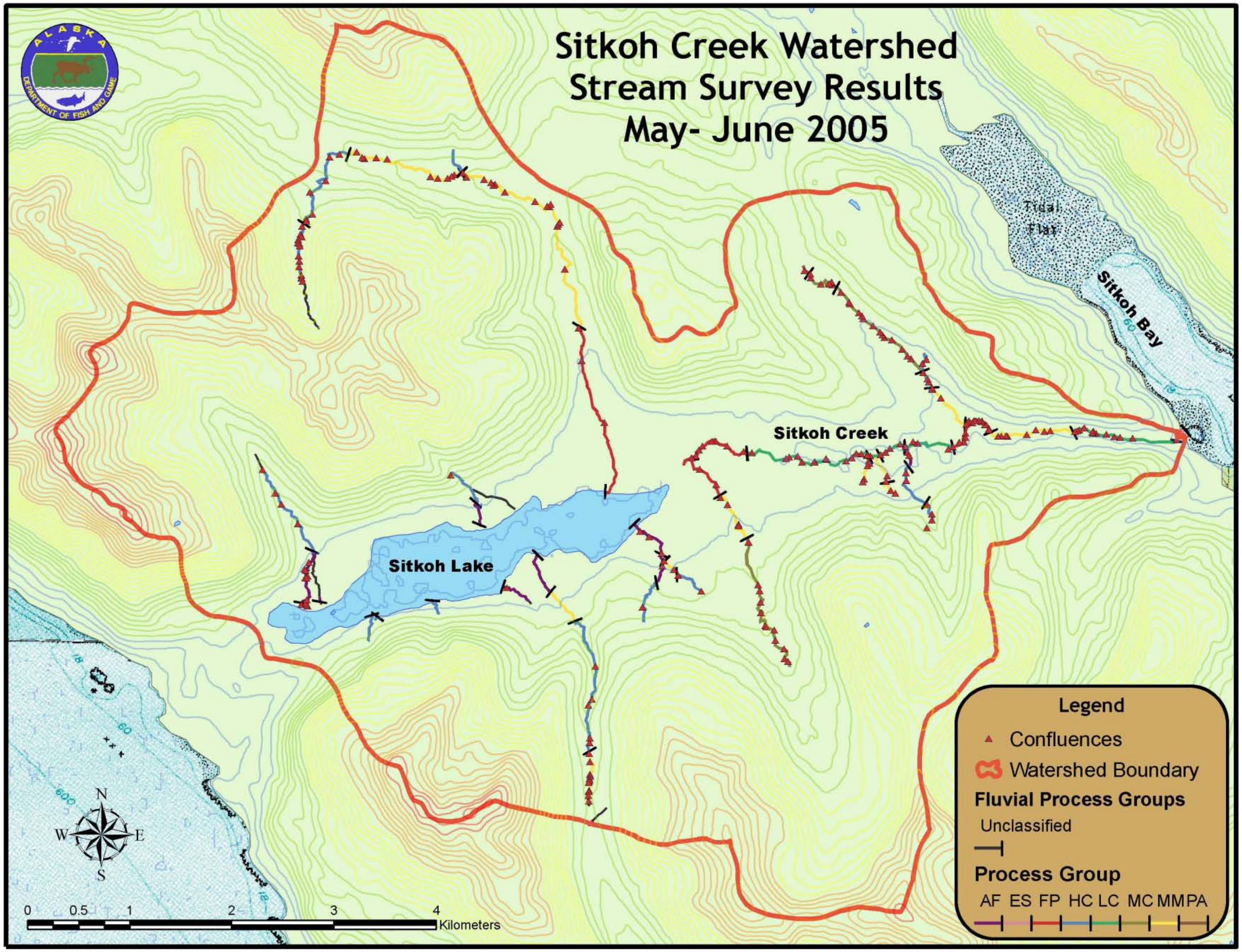
l_i = length of reach *i*.

As we surveyed each stream reach, macro-pools were counted. A detailed definition of macro-pools is included in Frenette et al. *unpublished a,* but in general they were defined by surrounding characteristics, such as average channel bed width, residual pool depth and the length of the macro-pools themselves. Macro-pool density for each reach was calculated similarly using Equation 3.

Table B1.–Qualifying dimensions of key wood pieces based on average channel bed width.

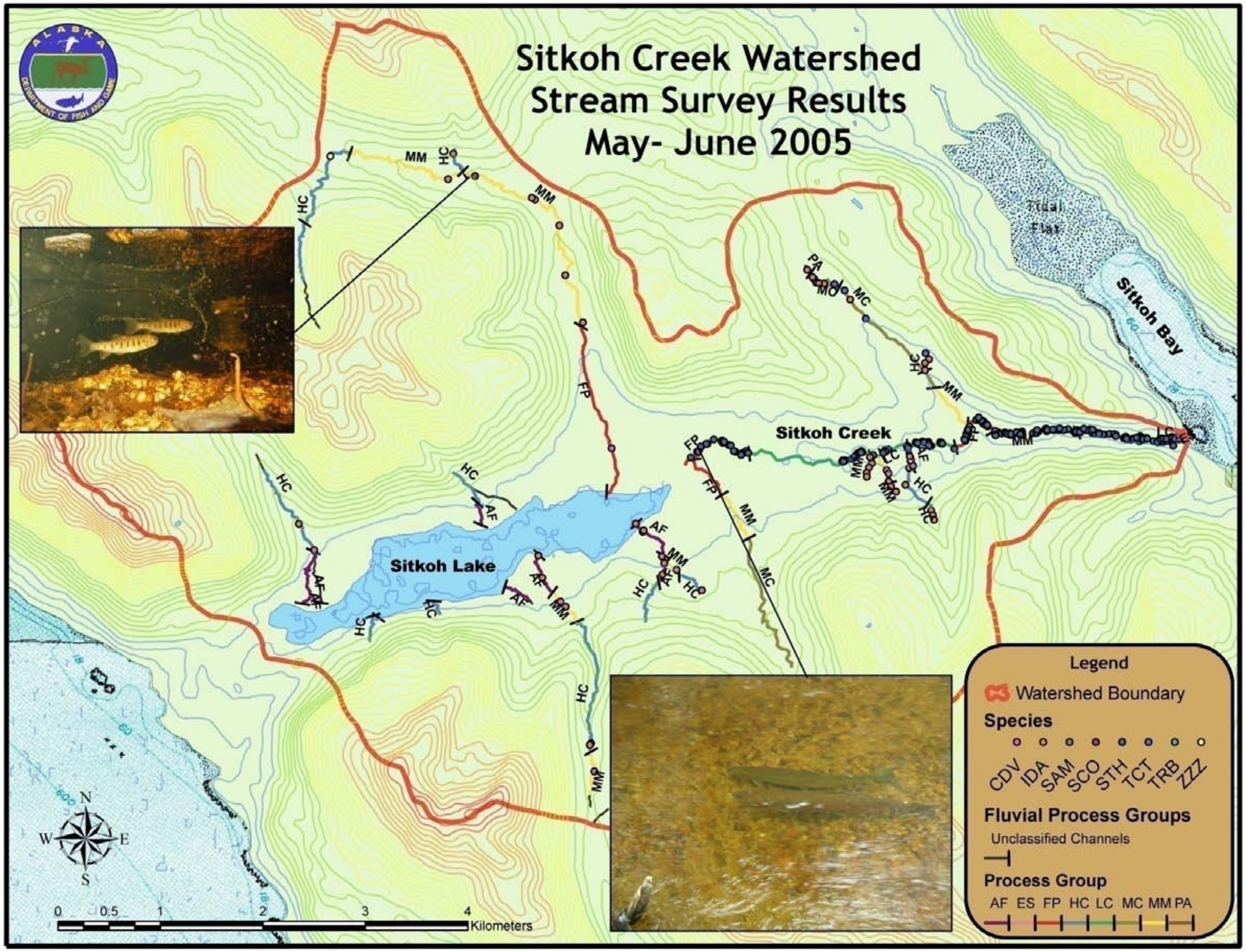
Average channel bedwidth (m)	Key piece diameter (m)	Key piece stem length (m)	Rootwad diameter (m)
0 - 4.9	0.3	> 3	> 1
5 - 9.9	0.3	> 7.6	> 3
10 - 19.9	0.6	> 7.6	> 3
≥ 20	0.6	> 15	> 3

APPENDIX C

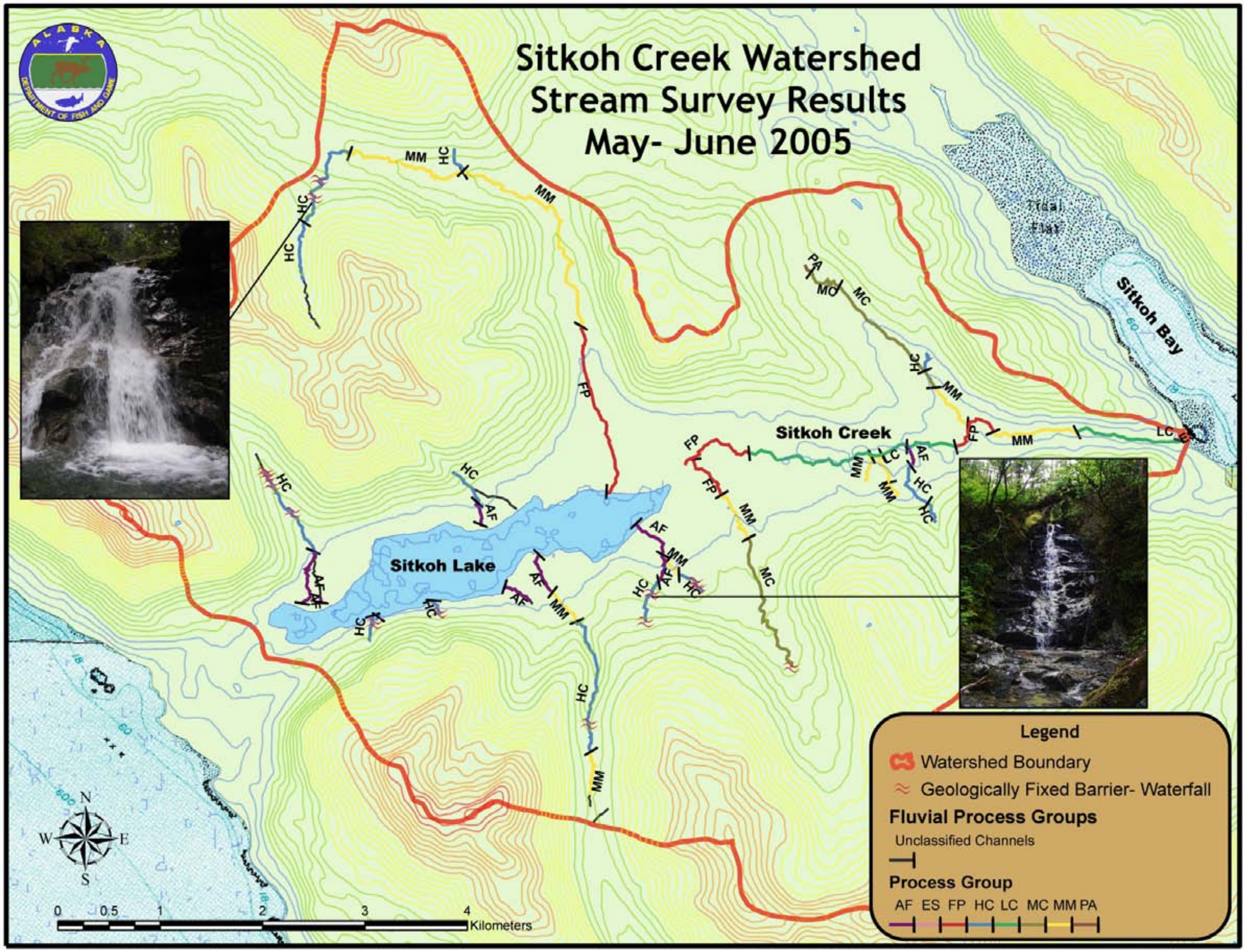


Appendix C1.–Stream habitat survey results indicating locations of stream reach confluences with tributaries and side channels.

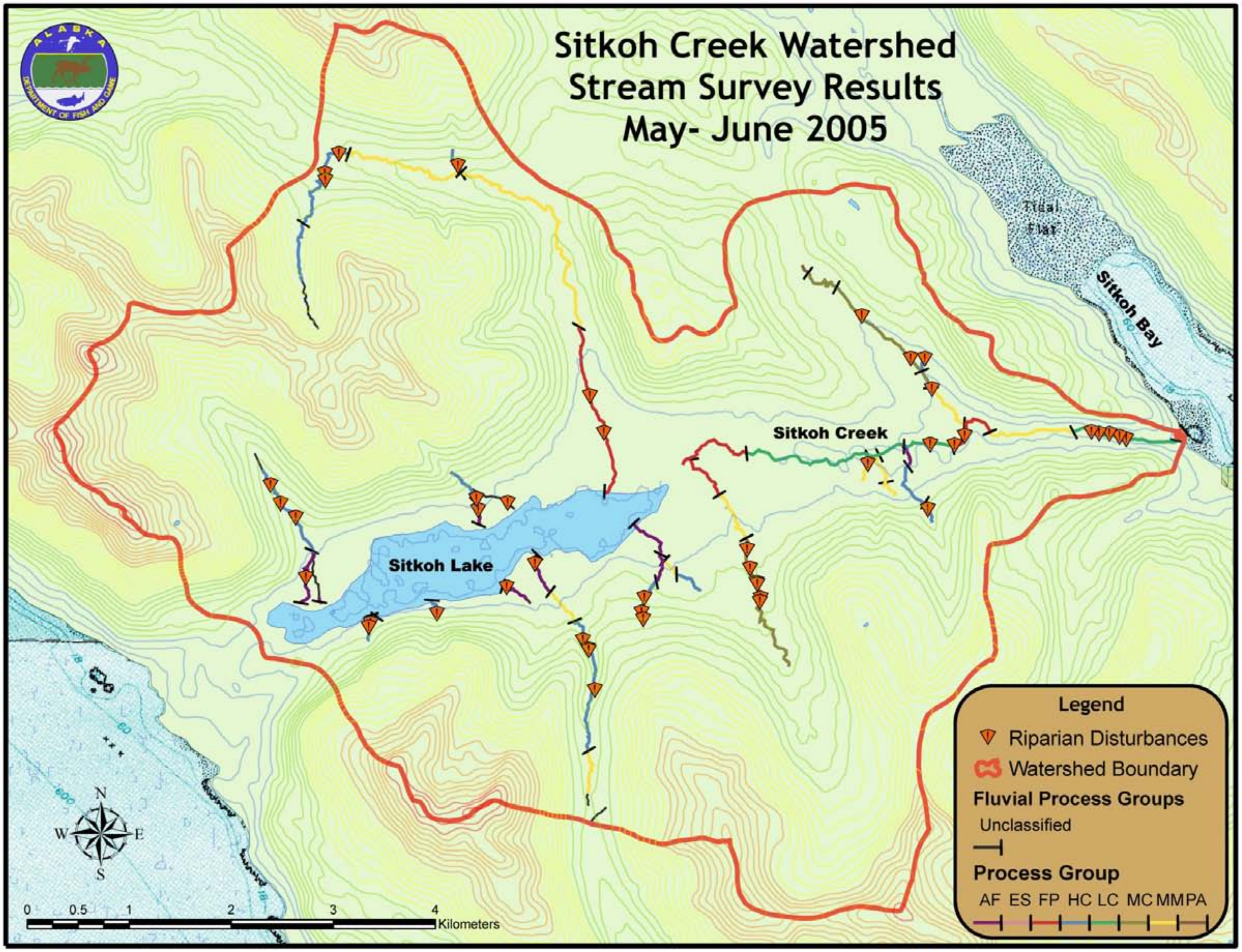
Appendix C2.–Stream habitat survey results indicating locations of ephemeral debris jams.



Appendix C3.–Stream habitat survey results indicating locations of fish observation points according to species.



Appendix C4.–Stream habitat survey results indicating locations of waterfalls, geologically fixed barriers.



Appendix C5.–Stream habitat survey results indicating locations of riparian disturbance.

APPENDIX D

Appendix D1.–List of computer data files archived from this study.

Data File	Description
Sitkoh _Hydro.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing all stream delineation for the Sitkoh Creek watershed
Sitkoh_Lake.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing all lake delineation for the Sitkoh Creek watershed
SKO_Features_ALL.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing all mapping features encountered during stream habitat surveys within the Sitkoh Creek watershed.
Sitkoh_FOP_ALL.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing all Fish Observation Points (FOP's) observed during snorkel surveys within the Sitkoh Creek watershed.
Sitkoh_Subbasins.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing all sub-basin delineation for the Sitkoh Creek watershed
Sitkoh_Creek_Watershed.shp	GIS shapefile (State Plane, NAD83 FIPS 5001 projection) containing for the Sitkoh Creek watershed.
FDS_05_DataArchive.xlsx	Excel spreadsheet containing data for Sitkoh Phase I FDS report tables and figures.