Final Report

HYPERSPECTRAL IMAGERY ACQUISITION AND ANALYSIS OF THE ELWHA RIVER CORRIDOR

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FLBS Report Number 191-06

March 31, 2006

Citation: Hauer, F. R., M. S. Lorang, P. L. Matson and D. C. Whited. 2006. Hyperspectral imagery acquisition and analysis of the Elwha River corridor. FLBS Report Number 191-06. Flathead Lake Biological Station, The University of Montana, Polson, MT.

PREFACE

This report is in fulfillment of an agreement between the University of Montana and the National Park Service (Olympic National Park) to conduct research related to Elwha River restoration. The work was carried out under Task Agreement No. UMT-67 authorized by Cooperative Agreement No. CA-1200-99-007 and Task Agreement No. J9500040277, administered cooperatively through the Northern Rocky Mountain Cooperative Ecosystems Studies Unit and the Pacific Northwest Cooperative Ecosystem Studies Unit.

INTRODUCTION

Background

The Elwha River in Washington State was historically one of the most productive salmon rivers in the Pacific Northwest (Wunderlich et al. 1994). Two dams were constructed on the river in the early 1900's, which eliminated anadromous salmon from about 90% of the basin. Furthermore, change in river habitat and structure below the lower dam as a result of modification in river discharge and sediment dynamics has led to departure from the natural range of variation in aquatic habitats and the interaction between the river and its floodplain. Throughout the world, and certainly in the Pacific NW of the USA, dams have greatly simplified complex river systems by interrupting the transport of sediment that, in conjunction with hydrologic river power, maintains the complexity of river floodplain habitats essential to the long term viability of salmonid populations (Hauer and Lorang 2004; Stanford et al. 2005). The reservoirs behind the dams also capture essential nutrients and organic materials that provide energy for downstream freshwater food webs. Sediments stored in the reservoirs no longer are deposited on floodplains or carried to the estuary and nearshore habitats of the Straits of Juan de Fuca.

The impending removal of the dams has offered a unique opportunity to explore restoration of river ecosystem processes and habitat essential to recovery of the Pacific salmonids that were so prevalent in the river prior to dam construction. Sampling of ecosystem attributes before and after dam removal in the Elwha River, will elucidate functional relationships among sediment and wood supply, formation and persistence of river and floodplain habitats, and resultant ecosystem dynamics essential to the eventual long-term sustainability of salmonid populations as they return to the upper Elwha watershed.

Ecological Concepts as Basis for the Research

The floodplains of gravel-bed rivers, such as the Elwha, encompass a wide array of habitat types associated with the magnitude, frequency and duration of flooding and the transport of sediment. Floodplains may be expansive or narrow. The river habitats, both on the surface and within the substratum, shift from one place to another in a dynamic mosaic mediated by the interaction between flooding, the generation of stream power, and the supply of sediment. River floodplains are constantly modified by erosion, deposition, and channel avulsion processes. These fluvial geomorphic processes lead to the destruction of old habitats and the development of new habitats in a spatially and temporally dynamic fashion referred to as a Shifting Habitat Mosaic (Stanford et al. 2005). The SHM is composed of habitats, ecotones, and gradients that cycle nutrients and possess biotic distributions that experience change through the forces associated with fundamental fluvial processes. Features reflecting the legacy of cut and fill alluviation (e.g., flood channels, springbrooks, scour pools, oxbows, wetland rills) may be present on young (i.e., regularly scoured channels) to very old surfaces (i.e., abandoned flood channels among the various forest stands).

Flooding, geomorphic change resulting from cut and fill alluviation, and subsequent succession of the floodplain vegetation, continually transform the SHM. Development and long-term successional patterns of riparian vegetation are determined, to a large degree, by the type and relative stability of the various floodplain surfaces. For example, the dynamics of cottonwood (*Populus spp.*) and willow (*Salix spp.*) reflect both the legacy of flooding and the frequent exposure of new surfaces of the SHM. For example, several studies from across western North America have revealed progressive declines in the extent and health of cottonwood riparia (Braatne et al. 1996; Mahoney and Rood 1998; Rood et al. 1998). The primary causes of these declines have been impacts related to damming, water diversions and the clearing of floodplain habitats for agricultural use and livestock grazing (Braatne et al. 1996). Studies conducted in the 1990's on vegetation of the Snake River floodplains concluded that declines in riparian cottonwoods were related to the suppression of seedling recruitment (Merigliano 1996). Since cottonwoods are a relatively short-lived tree (100-200 years), declines in seedling recruitment over a 50 year period led to the widespread restructuring of the age class distribution of the communities toward old individuals, which if left unchecked eventually leads to loss of function in riparian ecosystems.

Further examples of cut and fill alluviation and floodplain processes affecting the SHM is seen in the variation in thermal regime. While the change in temperature is particularly striking along the longitudinal gradient of a river (Hauer et al. 2000), there are surprising departures from this general pattern in which there may be extensive variation in temperature correlated with increased complexity of floodplain systems. Since the spatial dimension of the river landscape is three dimensional, incorporating the river channel, surface riparian and hyporheic habitats into a river corridor as an integrated ecological unit, river floodplains are segments along the river corridor where not only is spatial complexity maximized; but also thermal complexity is maximized. This is very evident in comparing thermal regimes of a main channel with backwater or side channel habitats, but just as profound in its ecological implications in floodplain reaches affected by hyporheic return flows to the surface.

Recent study has shown that pond and springbrook habitats located on large river floodplains may have steep thermal gradients exceeding 10^{o}C over less than 2 m in vertical strata. Thus, thermal complexity, associated with spatial complexity on large river floodplains, provide an increased abundance of riverine habitats and regimes (Stanford 1998). Thus, the hydrologic and geomorphic processes that so profoundly affect the easily observed habitat mosaic of surface features on a floodplain are equally influential upon a subsurface habitat mosaic.

The three principal concepts to grasp that underpin this work are: 1) that the Shifting Habitat Mosaic of river floodplains is spatially and temporally dynamic, 2) that the SHM is the essential template that supports the biodiversity, complexity and production of the river system, and 3) the SHM is sustainable only through geomorphic change which is driven by river dynamics. In other words, the SHM is driven by a temporal process that may be fast or slow and results in biotic responses that reflect the spatial heterogeneity that is a legacy of past geomorphic work and change. A fundamental feature of the SHM is that it principally functions at the landscape spatial scale and is profoundly influenced by the frequency and intensity of flooding and the ability of the river “to do work” through the processes of cut and fill alluviation.

Project Objectives and Tasks

There were two main objectives with this research: 1) link remotely sensed hyperspectral imagery with ground-truthing of hydraulic variables to assess aquatic habitats, and 2) provide remotely sensed hyperspectral imagery as background data for assessing the river condition prior to dam removal. As an additional objective, we are working with Dr. Jeff Braatne to link the hyperspectral imagery with riparian vegetation to assess floodplain characteristics.

Specific Tasks:

1. *Acquisition and post-processing of hyperspectral data (remote-sensed digital data) of the Elwha River Corridor from the upper portion of the Geyser Basin floodplain to the Strait of Juan de Fuca (via AISA hyperspectral sensor deployed from high performance, slow-flying aircraft).*
2. *Analysis of hyperspectral data for ecological attributes and floodplain-scale metrics.*
3. *Assistance with riparian and wetland vegetation assessments along the Elwha River Corridor.*

METHODS

Remote Sensing

On August 19 and 20, 2003, hyperspectral remotely sensed data were collected over the Elwha river corridor from the upper Geyser Basin floodplain to the Straits of Juan de Fuca. The Elwha river corridor was separated into 6 reaches for remotely sensed data collection (Figure 1). Each reach was covered by 4 to 7 flightlines.

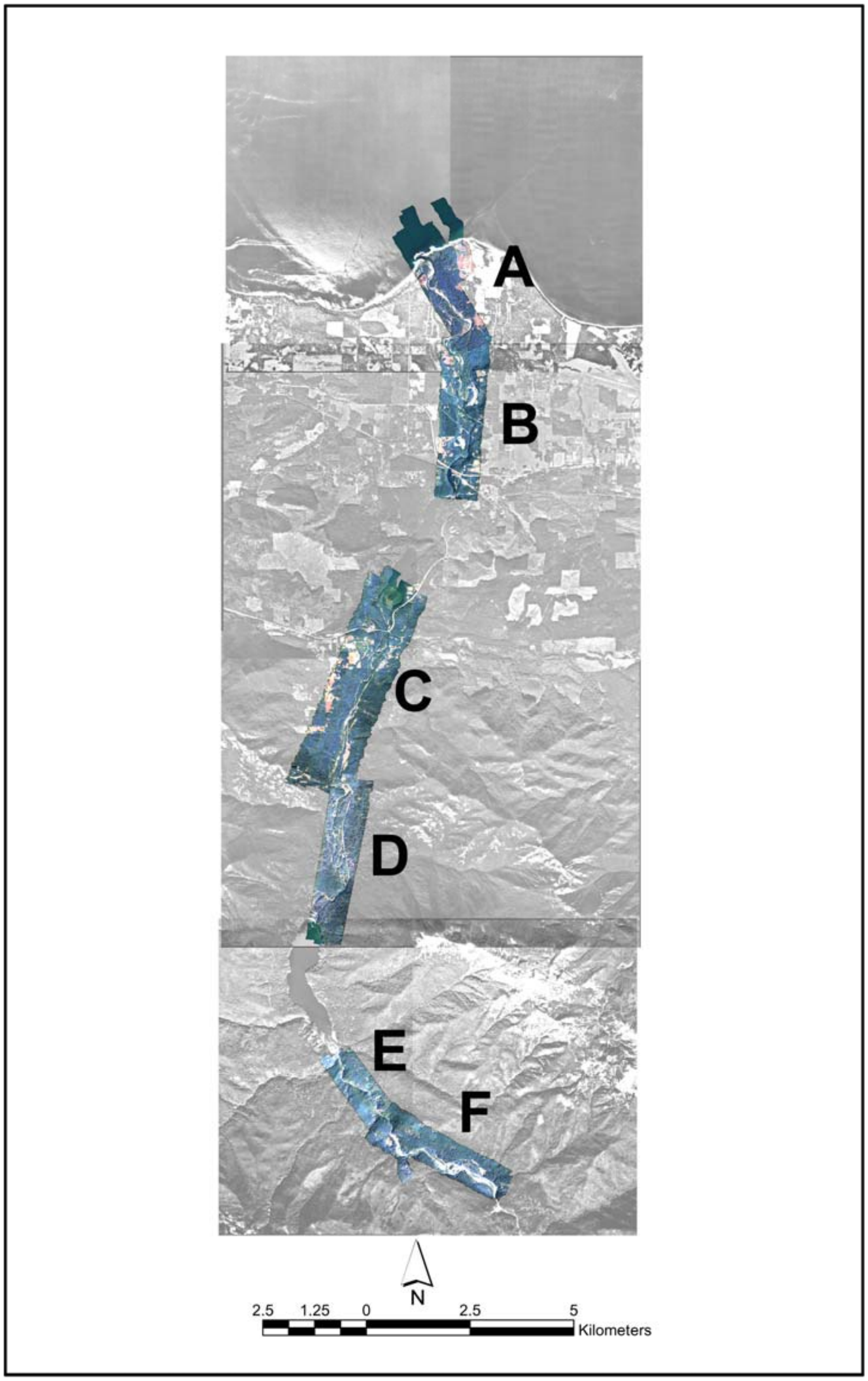

Figure 1. Elwha River corridor showing the locations of remotely sensed Hyperspectral Image data collection.

In early October 2003, approximately two months after the 2003 hyperspectral data collection, the Elwha experienced very high discharge. Hyperspectral image data were collected the following late summer on September 30, 2004.

Remotely sensed data were collected with an AISA hyperspectral imagery system from Spectral Imaging, Oulu, Finland. The AISA system consists of a compact hyperspectral sensor head, miniature GPS/INS sensor, and system control and data acquisition unit. The AISA hyperspectral sensor is operated from the aircraft at the height (1000m) and speed (87kts) required to obtain a 1x1m pixel resolution. Waveband configuration for digital data acquisition is from 256 individual spectral wavebands (400 to 950 nm) arrayed into 20 aggregate bands. The system also requires an aircraft top-mount of a real-time fiber-optic downwelling irradiance sensor (FODIS) that provides radiometric correction data for post-processing of surface reflectance. The GPS/INS is a Systron-Donner C-MIGITS III with Digital Quartz Inertial measurement unit (DQI) which tags each image line from the AISA sensor. The GPS coordinates are derived from 10 to 12 GPS satellites depending on satellite positions. The GPS data are linked with the inertial referencing of the C-MIGITS III to correct for pitch, roll and yaw of the aircraft during data acquisition. Data are stored during acquisition on a hot-swap removable U160 SCSI drive.

The remote sensing data were collected along predetermined flight lines oriented along the long axis of the study floodplains and having flight line overlaps of 40-50%. All data were collected within a time period of 2.0 hrs either side of solar noon. We selected the clearest days possible during a sampling interval to capture flow and vegetation attributes that were targeted to maximize the quality of the imagery data.

Individual flight lines were cross-referenced with existing Digital Ortho Photo Quadrangles (DOQs) to examine the spatial positioning of each flight line. If an individual flight line needed further geo-rectification, then additional GCPs (ground control points) were added to improve the rectification in a given flight line. All geo-rectified flight lines had a mean RMS (root mean square) error of less than 4 meters. The RMS error is an estimate of how close a given pixel is to its true location. Once all flight lines were geo-rectified for a given reach, they were then stitched together to create a final mosaic. Minor color-balancing between flight lines were applied during the mosaiking process. All geo-rectification and mosaiking were completed in ERDAS Imagine 8.5.

In addition to the hyperspectral image data collection, we added another instrument during summer 2004 to our data collection array. Thus, for the September 30, 2004 mission, we collected ultra-high resolution multispectral images (3-band) with a ground resolution of approximately 5cm. These data were used to verify fine resolution uncertainties in the hyperspectral data and serve as a data source available for future research.

Water Depth and Velocity Ground-truth

A Sontek RS3000 Acoustic Doppler velocity-Profiler (ADP) was used to acquire detailed water depth and vertical profile measurements of flow velocity along channel reaches within the study floodplains. ADP survey data were collected in September 2004.

The ADP uses 3 transducers to generate a 3 MHz sound pulse into the water. As the sound travels through the water, it is reflected in all directions by particulate matter (e.g., sediment, biological matter) carried with the flow. The sonar signal is most strongly reflected from the bottom substrate providing a measure of water depth. Some portion of the reflected energy travels back toward the transducer where the processing electronics measure the change in frequency as a Doppler shift. The Doppler shift is correlated to the velocity of the water. The ADP operates using three transducers generating beams with different orientations relative to the flow of water. The velocity measured by each ADP transducer is along the axis of its acoustic beam. These beam velocities are converted to XYZ (Cartesian) velocities using the relative orientation of the acoustic beams, giving a 3-D velocity field relative to the orientation of the ADP. Since it is not always possible to control instrument orientation, the ADP includes an internal compass and tilt sensor to report 3-D velocity data in Earth (East-North-Up or ENU) coordinates, independent of instrument orientation. Thus, it is possible to determine the mean flow velocity in separate cells through the water column oriented perpendicular to the flow field. By measuring the return signal at different times following the transmit pulse, the ADP measures water velocity at different distances from the transducer beginning just below the water surface and continuing to the bottom. The water velocity profile is measured and displayed as a series of separate 15 cm deep cells from top to bottom. Each recorded cell measurement is the average of several hundred measures over a 5 second time intervals.

We deployed the ADP from a small cataraft that is held and manipulated into various aquatic habitats by a field operator based up stream. Both velocity profile data and depth data were correlated spatially by linking a GPS (Global Positioning System) receiver with the position of the ADP. During data acquisition the ADP was maneuvered back and forth across the channel to obtain data from as full an array of aquatic habitats, depths and velocities as possible. Both the ADP and GPS data were recorded simultaneously on a field laptop computer. The ADP data were then processed to create an integrated velocity value (average velocity for an individual ADP profile), as well as a depth value for each GPS location.

Aquatic Classification of Hyperspectral Data

An unsupervised classification approach (ISODATA, Iterative Self-Ordering Data Analysis, Tou and Gonzalez 1977) was used to generate similar categories of spectral reflectance. Once an unsupervised classification of spectral reflectance was generated, the ADP data were distributed in the GIS environment to aggregate classes and assign unique depth and velocity categories. All reaches were classified into 4 depth categories (< 0.25, 0.25 – 0.75, 0.75 – 1.25, and > 1.25 m) and 4 velocity categories (< 0.25, 0.25 – 0.75, 0.75 – 1.25, and > 1.25 m/s). These initial classifications of water depth and flow velocity provided the basis for modeling depths and velocities at both higher and lower river stages. The ranges for each category were a function of the range of depths and flow velocity obtained with the ADP and the resolution that can be achieved from the hyperspectral imagery.

Vegetation Classification of Hyperspectral Data

A combination of supervised and unsupervised classification was used to produce a land cover map for the D-reach (between the reservoirs). First, an unsupervised classification was used to discriminate between vegetative cover and non-vegetative cover (i.e. vegetation vs cobble and water). This was followed by a supervised classification approach for the vegetative cover. To help discriminate among different vegetation types, homogeneous stands of the varying cover types (e.g., cottonwood, willow, conifer, cobble) were identified and associated with specific hyperspectral signatures. These specific imagery signatures were used as “training areas” to classify the image into the different land cover types. Mean spectral signatures were calculated for each cover type and subsequently used in a supervised classification. Using the spectral signatures, the Mixed Tune Matched Filtering (MTMF) algorithm in ENVI (RSI 2000) was then applied to the vegetative component of the imagery to discriminate the varying vegetation types. This method of classifying vegetation is a significant departure from approaches involving digitizing and photo-interpretation. We were able to take this approach of conducting an integrated supervised and unsupervised classification because of the application of the hyperspectral imagery allowing vegetation specific differentiation.

DATA PRESENTATION

This project specified the acquisition of remotely sensed hyperspectral data, collection of acoustic data from aquatic habitats to ground-truth the imagery, and to work with others (George Pess and Jeff Braatne) to develop metrics of habitat analysis in both aquatic and riparian environments. Below we present example data showing a single reach (Reach D) of the Elwha River with figures of the raw hyperspectral image (Figure 2), an illustration of channel location in 2003 and 2004 showing spatial change resulting from the October 2003 high discharge event (Figure 3), classification of water depth and velocity (Figures 4, 5, 6 and 7), and vegetation classification (Figure 8).

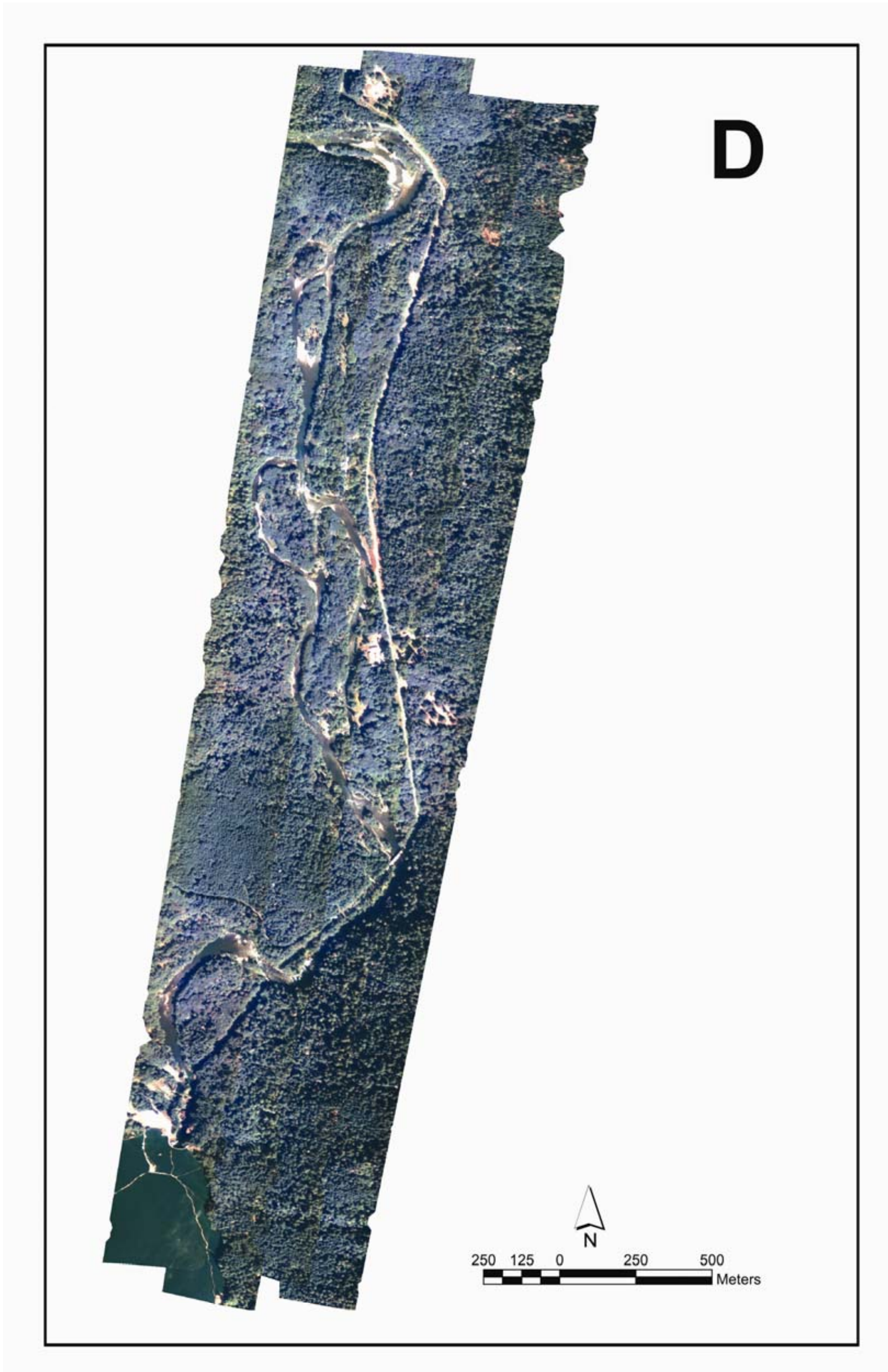

Figure 2. Raw Hyperspectral Image of Reach D of the Elwha River.

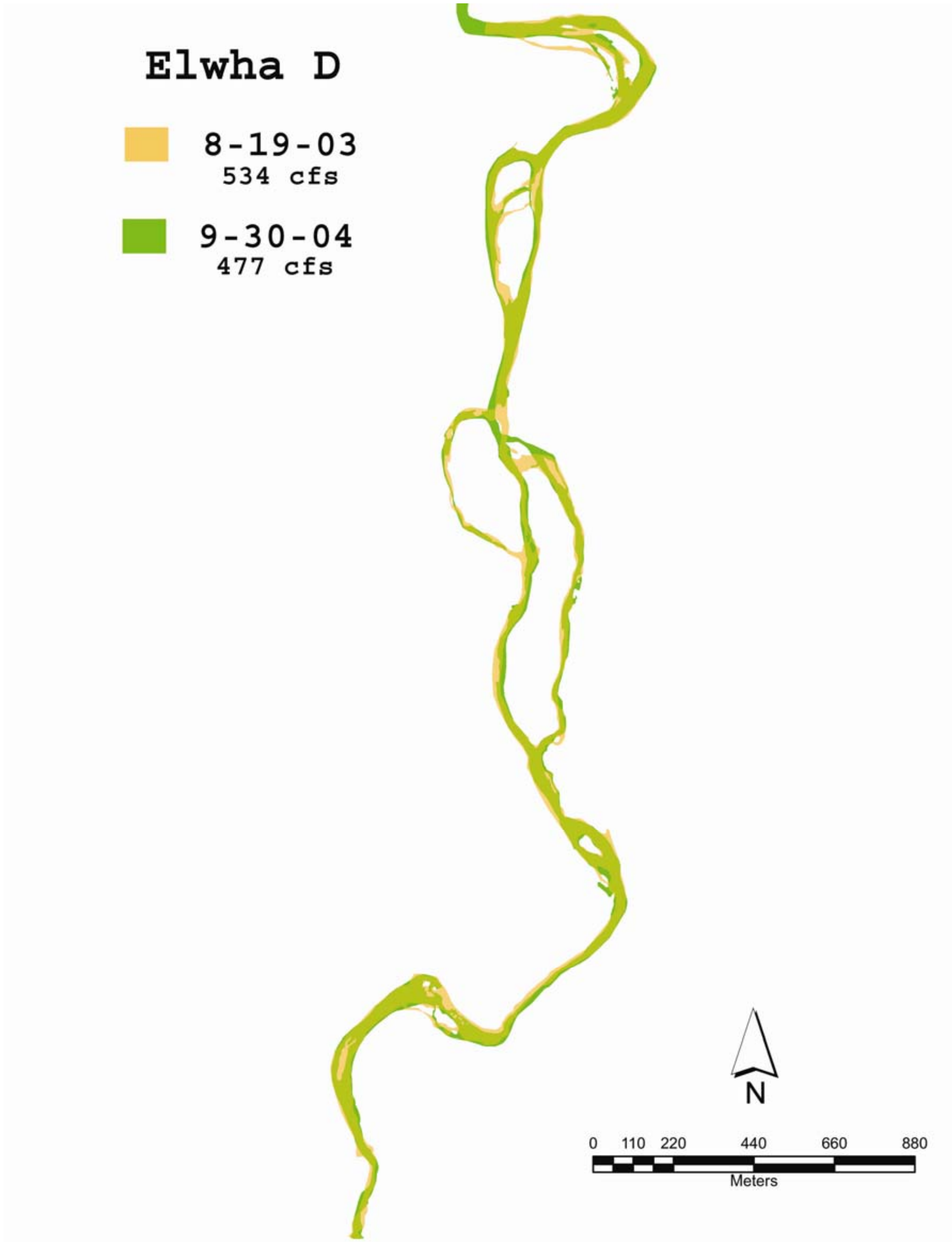

Figure 3. Spatially explicit location of the Elwha River channel in 2003 and 2004.

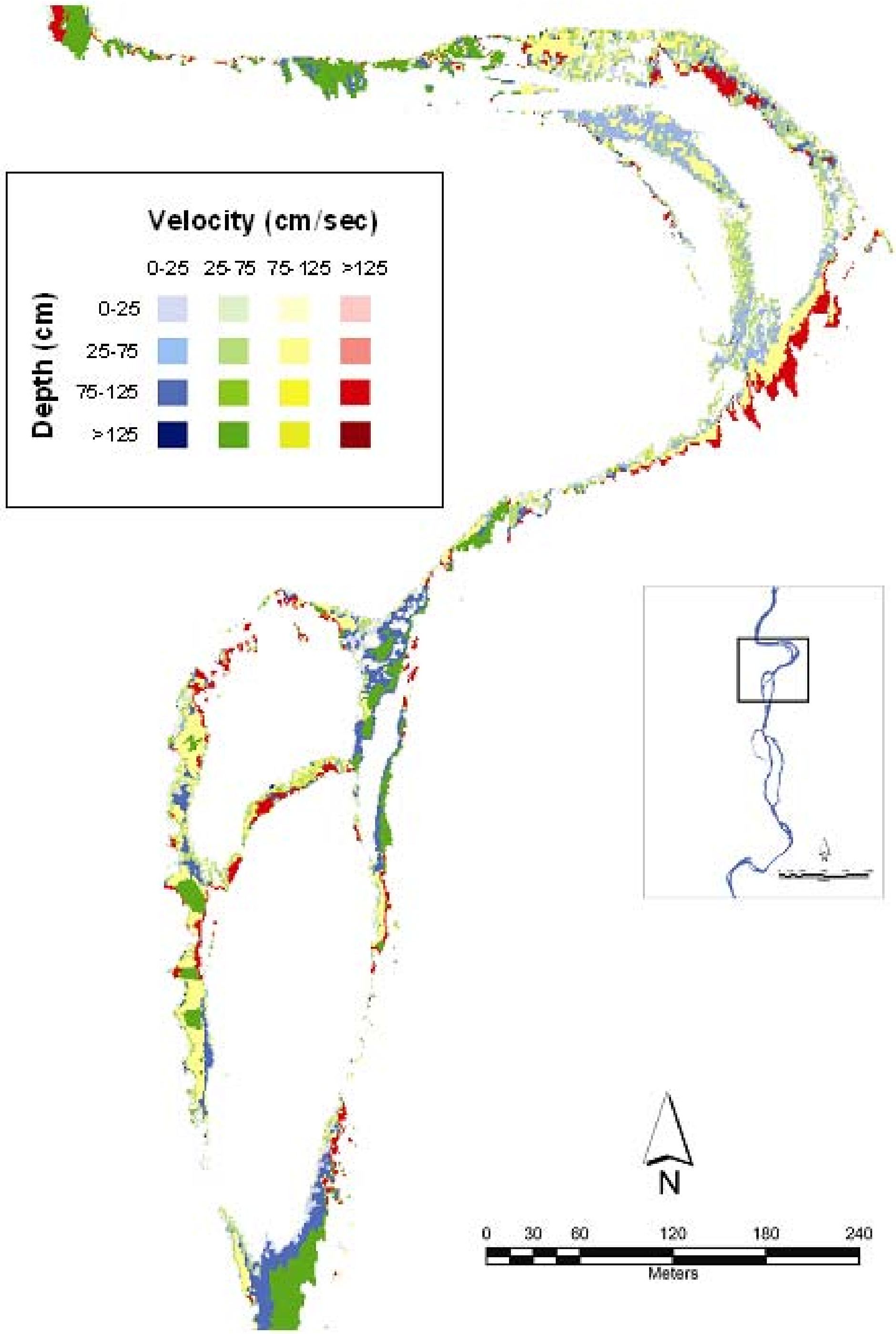

Figure 4. Depth and velocity classification of Segment 1 of Reach D of the Elwha River (2004).

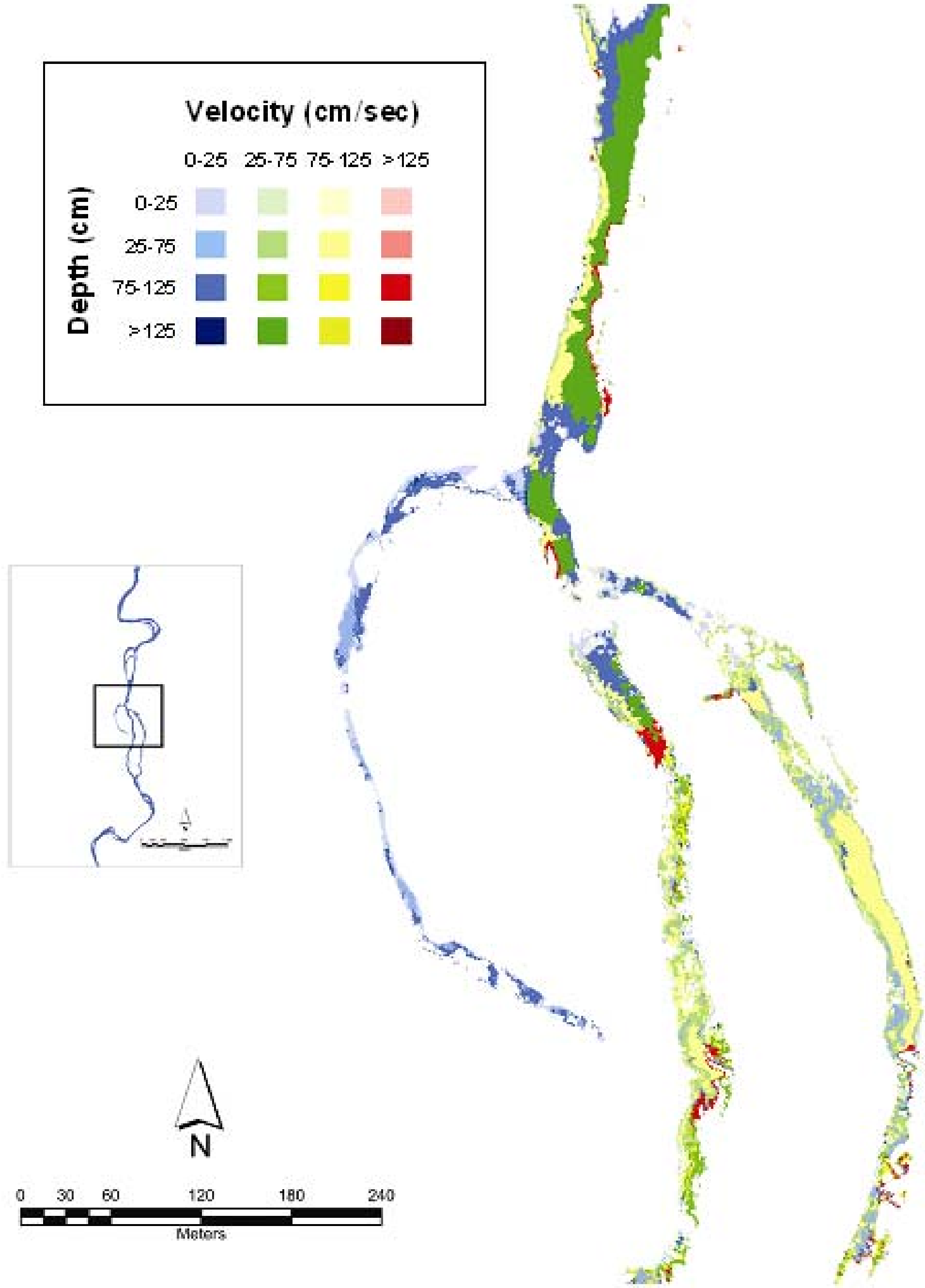

Figure 5. Depth and velocity classification of Segment 2 of Reach D of the Elwha River (2004).

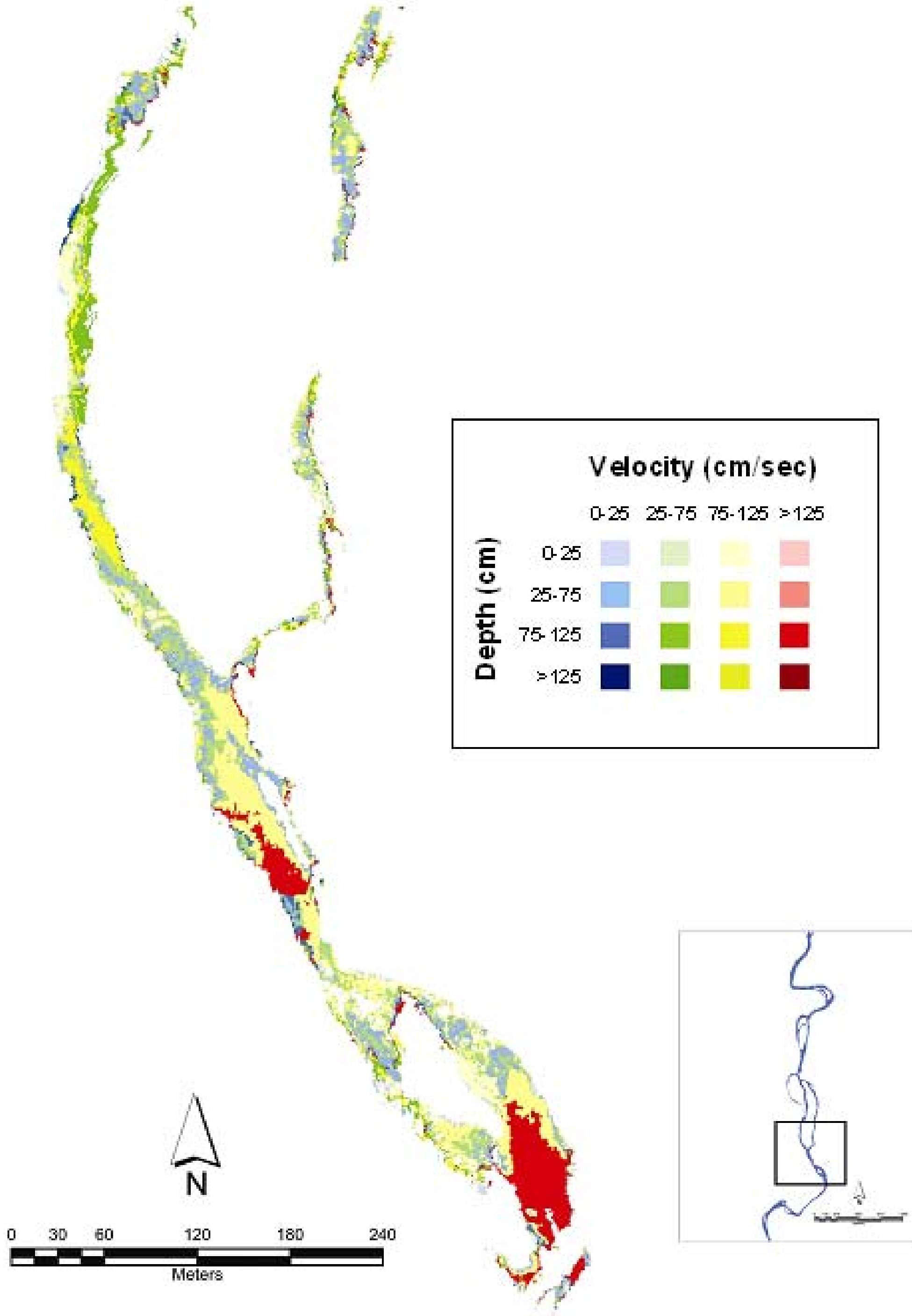

Figure 6. Depth and velocity classification of Segment 3 of Reach D of the Elwha River (2004).

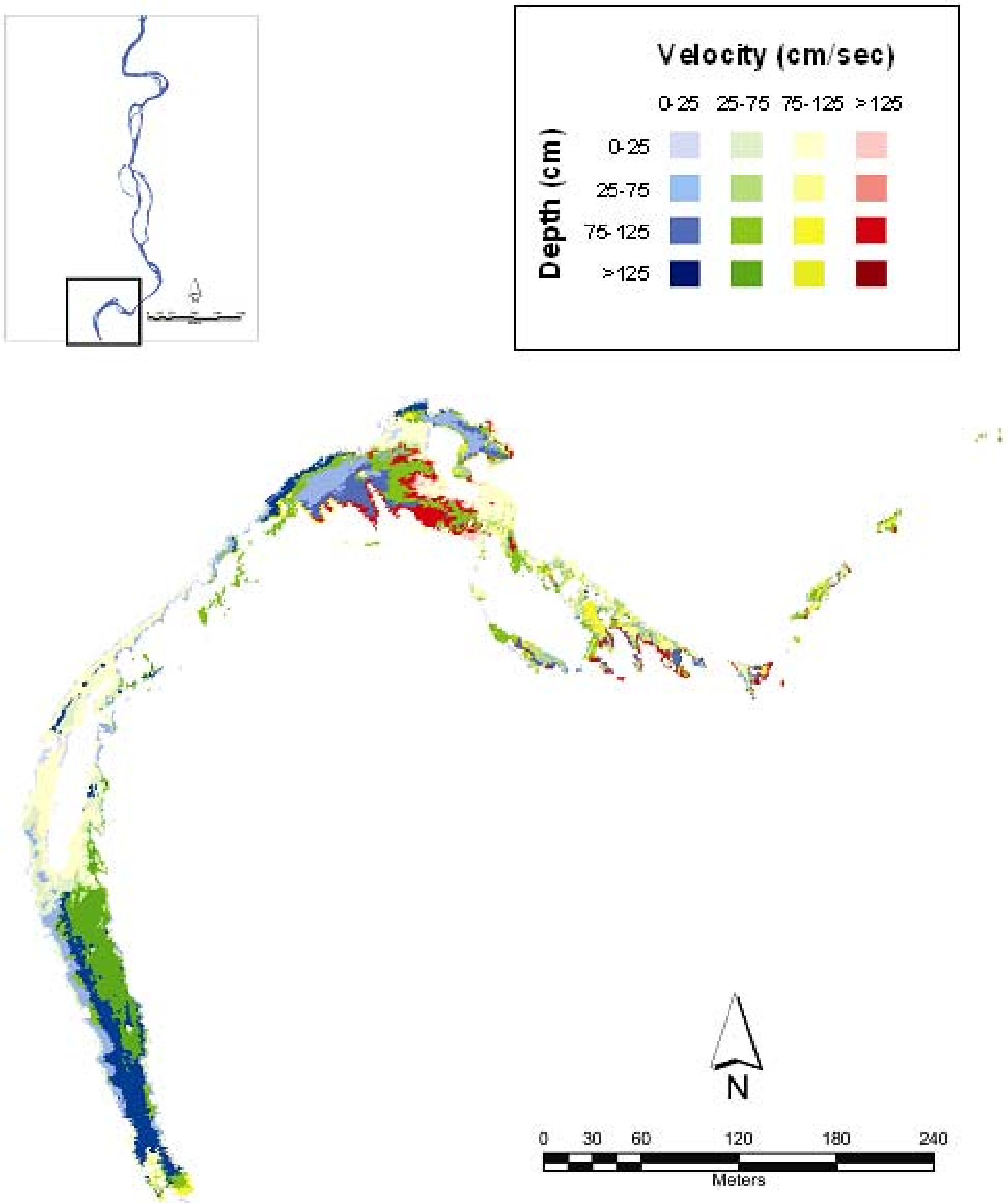

Figure 7. Depth and velocity classification of Segment 4 of Reach D of the Elwha River (2004).

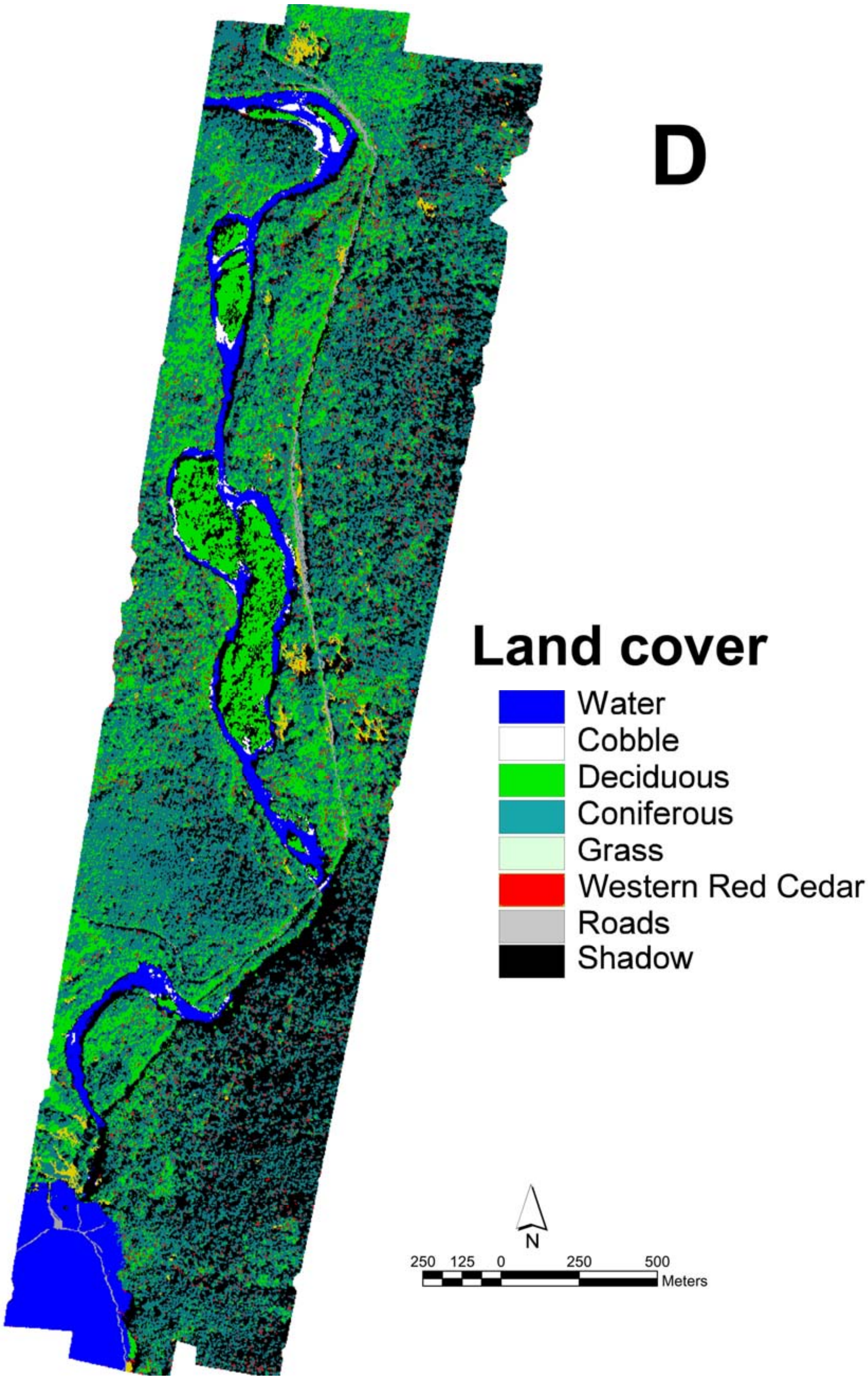

Figure 8. Vegetation classification of Reach D of the Elwha River (2004).

Hyperspectral and High Resolution Data

All hyperspectral and high resolution data are presented on the accompanying DVD data disk for long-term storage and easy access. Data are also maintained at Flathead Lake Biological Station < http://www.umt.edu/flbs/ >. Data are organized by reach/data type/classification.

All data are the intellectual property of FLBS and The University of Montana. All cooperators in the Elwha Research Consortium are free to use these data for presentation purposes and to develop new hypotheses and research objectives. Use of these data must be accompanied by citation of the source data and location.

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