Decision-Based Fusion for Improved Fluvial Landscape Classification Using Digital Aerial Photographs and Forward Looking Infrared Images

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Abstract
Riverine landscapes associated with large dynamic floodplains provide a complex array of habitats for fish. Mapping and quantitative assessment of the habitats poses a major challenge. This study uses high spatial resolution airborne digital photographs and forward-looking infrared (FLIR) images, simultaneously acquired in spring 2005 over a 12 river kilometer section of the Unuk River in Southeast Alaska to map macro habitat indicators for Pacific salmon such as large woody debris (LWD), water channels, sand/gravel bars, and riparian vegetation. Image processing revealed that LWD could best be extracted using contextual information from the digital photos. River channel water had prominent shadows cast from neighboring trees and could not be accurately classified using digital photos, but could be well-delineated using unsupervised classification of the FLIR images. All other classes showed up well using supervised classification of digital photos. Using a decision-based fusion approach, the best individual classification results obtained from the digital photos and FLIR images to generate an improved fluvial landscape classification map (land-cover map). Using a decision-based fusion method resulted in an overall classification accuracy of the study area to 84.29 percent, compared to 77.00 percent using supervised classification of aerial photos alone. This appears to be first time that high-resolution airborne thermal images have been used for fluvial landscape classification, and the study clearly demonstrates the value of using thermal images and decision-based fusion approach for improved land-cover classification.

Introduction/Background
Fluvial landscapes associated with undisturbed river floodplains are inherently dynamic in nature providing a complex array of habitats (Hynes, 1975; Sedell *et al.*, 1989). Natural flood pulses maintain the integral relationship between the river and the lateral floodplain constantly altering river channel position, nutrient cycling, and ultimately, the habitats available to fish (Stanford and Ward, 1992; Junk *et al.*, 1989). The complex structure of floodplains and their related landscape elements (e.g., gravel bars, multiple channels, large woody debris (LWD), and floodplain patches) describe macro habitat indicators for fish (Poole, 2002). LWD refers to wood pieces (i.e., entire fallen trees, branches, rootwads) typically larger than 10 cm in diameter and 2 m in length within stream and river ecosystems (Bilby and Ward, 1989; Maser and Sedell, 1994).

Stream habitat surveys describing fish habitat and fish habitat indicators have traditionally been accomplished by foot surveys conducted on the ground. Ground-based habitat surveys quantitatively and qualitatively characterize the physical habitat using a bottom up approach. This approach works well for smaller stream systems, where measurements can be obtained throughout an entire system. However, for larger rivers, conducting habitat surveys on the ground is extremely difficult given their size and typically complex habitat. Due to time and logistical constraints (especially in remote locations) and the fact that these areas lack an easily repeatable temporal component, comprehensive ground surveys are considered ineffective (Poole *et al.*, 1997; Legleiter *et al.*, 2002; Leckie *et al.*, 2005). Remote sensing offers an alternative method that provides a top down approach to quantitatively assess lateral, longitudinal, and vertical landscape attributes of these larger river systems (Johnson and Gage, 1997; Bryant and Gilvear, 1999; Fausch *et al.*, 2002).

Advancements in satellite remote sensing of riverine landscapes have been commensurate with that of technological developments of satellite sensors and image processing techniques (Muller *et al.*, 1993; Smith, 1997; Mertes, 2002). In the 1980s and 1990s, several satellites such as Landsat, SPOT, and ERS provided medium spatial resolution data (10 m to 30 m) which were useful for mapping large high order channel morphology and macro habitat (Salo *et al.*, 1986; Ramasamy *et al.*, 1991; Mertes, 2002). However, pixels of such size are still spatially limiting in many river studies, where ultimately the spatial resolution of the remotely

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