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A classification-based assessment of the optimal spectral and spatial resolutions for Great Lakes coastal wetland imagery

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Abstract

We analyzed hyperspectral airborne imagery (CASI 2 with 46 contiguous VIS/NIR bands) that was acquired over a Lake Huron coastal wetland. To support detailed Great Lakes coastal wetland mapping, the optimal spatial resolution of imagery was determined to be less than 2 m. There was a 23% change in classification resiliency using the SAM classifier upon resampling the original 1-meter, 18-band imagery to 2-meter pixels, and further classifications with larger pixels (4 and 8 m) increased overall classification change to 35% and 50%, respectively.

We performed a series of image classification experiments incorporating three independent band selection methodologies (derivative magnitude, fixed interval and derivative histogram), in order to explore the effects of spectral resampling on classification resiliency. This research verified that a minimum of seven, strategically located bands in the VIS–NIR wavelength region (425.4 nm, 514.9 nm, 560.1 nm, 685.5 nm, 731.5 nm, 812.3 nm and 916.7 nm) are necessary to maintain a classification resiliency above the 85% threshold. Significantly, these seven bands produced the highest classification resiliency using the fewest number of bands of any of the 63 band-reduction strategies that were tested.

Analyzing only derivative magnitudes proved to be an unreliable tool to identify optimal bands. The fixed interval method was adversely influenced by the starting band location, making its implementation problematic. The combined use of derivative magnitude *and* frequency of occurrence appears to be the best method to determine the “optimal” bands for a wetland mapping hyperspectral application.

Keywords: Hyperspectral imagery; Spectral Angle Mapper (SAM); Great Lakes; Coastal wetlands; Spectral resolution; Spatial resolution; Optimal bands

1. Introduction and rationale

Medium- to large-scale aerial photography has proven to be a fast, accurate, and relatively inexpensive method by which wetland boundaries, botanical changes, and areal extent can be mapped (Mitsch & Gosselink, 2000). Two characteristics limit the applicability of aerial photography for detailed wetland mapping tasks: 1) the limited amount of spectral information (one to three bands) contained in each image (Jensen et al., 1986), and 2) its non-digital format (Hardisky et al., 1986). The utility of satellite remote sensing systems for detailed wetland characterization, on the other hand, is limited by their combined spatial and spectral resolutions. Current spaceborne sensors with fine spatial resolution have only a few broad spectral bands (e.g., IKONOS, QuickBird and OrbView-3), while narrow-band satellite sensors typically have coarse spatial resolution (e.g., MODIS). Thus, both aerial photography and currently available satellite imagery are sub-optimal for detailed wetland mapping.

Hyperspectral sensors record 3-dimensional imagery (the third dimension being the spectral range) creating an enormous amount of data for image processing, storage and transmission (Chang et al., 1999). Cutting edge airborne and satellite hyperspectral sensors are capable of recording hundreds of discrete, narrow bands across the visible, NIR and SWIR portions of the electromagnetic spectrum, and this ability will become more mainstream as technology advances. The end-

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user community will need to know the location of bands *optimal* for their specific area of application in order to achieve the potential improvements in classification accuracy these hyperspectral imagers present (Thenkabail et al., 2004). Guidelines to assist end-users in the efficient selection of these optimal bands are crucial because the number of potential band combinations in a hyperspectral image is typically quite large (e.g., there are nearly 44,000 possible four-band combinations in a 16-band image).

This research tested two general hypotheses through a series of hyperspectral image classifications. First, band selection strategies (i.e., reducing the number of bands) can be effectively guided by derivative-based, statistical analysis of coastal wetland plant spectra. Second, the spatial heterogeneity of Great Lakes coastal wetlands is best captured by digital imagery with a spatial resolution smaller than 5 m.

Becker et al. (2005) analyzed in-situ plant reflectance measurements from a number of common plant species in Great Lakes coastal wetlands. This previous study spectrally resampled hyperspectral plant signatures to match the 48 contiguous, visible and near-IR bands of 4-meter CASI 2 imagery. Using an approximated 2nd-derivative methodology, Becker et al. (2005) identified seven key spectral bands in the VIS–NIR that were judged to have increased power for differentiating vegetation types within the coastal wetlands of the Great Lakes. These bands were similar to the NIR and visible bands identified by Schmidt and Skidmore (2003) in a similar study.

In this paper, we present the results of our tests of the efficacy of several band reduction strategies through the classification of airborne, 4-meter, hyperspectral imagery at both its full spectral resolution (i.e., 46 bands, 11.6–11.8 nm wide) and at many degraded spectral resolutions. Becker et al. (2005) established several wavelength domains across the visible and NIR spectrum from which the predominant band was selected based on histograms of derivative magnitude. In order to provide a more robust set of comparable classification outcomes, two additional band-selection methodologies – derivative magnitude and fixed interval – were implemented for this paper. Lastly, we test the hypothesis that the spatial heterogeneity of coastal wetlands in the Great Lakes is best captured by digital imagery with a spatial resolution smaller than 5 m by sequentially classifying 1-meter CASI 2 imagery at its native spatial resolution (1 m) and at several spatially-degraded resolutions.

2. Methods

2.1. Study area

The Wildfowl Bay island complex is located along the southeastern shoreline of Saginaw Bay in east-central Lower Michigan. Saginaw Bay inundates a shallow, gently slopping glacial lake plain underlain by dolomitic limestone, outcroppings of which form the foundations of many of the permanent islands in the region (Chow-Fraser & Albert, 1998). Horseshoe Bay is a shallow, protected embayment within the Wildfowl Bay island complex encircled by Maisou, Middle Grounds, and Heisterman islands (Fig. 1).

2.2. Imagery

Under a contract with Ducks Unlimited USA, ITRES, Inc. (www.itres.com) captured high-resolution, hyperspectral imagery over the study area on September 11, 2000 using their Compact Airborne Spectrographic Imager-II (CASI 2). Both 1-meter resolution imagery with 18 non-contiguous bands and 4-meter resolution imagery with 46 contiguous bands were acquired. Table 1 summarizes the center wavelengths and bandwidths for the two imagery sets. The CASI 2 is a programmable, imaging spectrometer, capable of recording over 200 contiguous bands throughout the visible and near-IR regions of the spectrum. However, there is an operational trade-off between the number of bands that can be captured and the pixel size at which they are imaged. The sensor constraints in place during the September 2000 imaging campaign allowed the selection of no more than 18 bands within the spectral range of the instrument when collecting 1-meter imagery. The spatial resolution had to be relaxed to 4 m before truly hyperspectral images could be recorded (i.e., numerous, narrow, contiguous bands across the VIS–NIR spectrum). Technological advancements now make it possible to record a larger number of bands at both spatial resolutions (ITRES, 2006; Personal Communication), but band choices still must be made when imaging at fine spatial resolutions.

The imagery was geo-referenced using an affine transformation and nearest neighbor resampling (there is less than 2 m of local relief in the imagery). The ground control points were bright-white plywood panels (2.25 m^2) that were installed just prior to the imaging overpass and for which sub-meter GPS positions were determined. The overall root-mean-square errors (RMSE) for the rectifications were sub-pixel for both data sets (0.796 m for the 1-meter imagery and 1.156 m for the 4-meter imagery).

A large, homogeneous gravel parking area near the mainland coast was captured in the imagery and served as a radiometric calibration surface. In-situ radiance measurements were recorded from this surface during the imaging campaign and were employed to transform the image data into relative percent reflectance utilizing the *Flat Panel Calibration* module in the ENVI image processing software (Research Systems, Inc., www.rsinc.com).

2.3. Image classification

All of the image classifications reported here were performed using the Spectral Angle Mapper (SAM) classifier in the ENVI image processing software (Research Systems, Inc., www.rsinc.com). SAM is a non-probability-based algorithm that separates image spectra according to a cumulative angular coefficient that is derived from each spectral data point. Fundamentally, there is an inverse relationship between the number of bands and the probability of a key band being removed that was associated with a subtle spectral feature needed to differentiate one or more classes. If only two bands were used, each spectrum would be reduced to a single, decision-space vector, and all subtle features would be lost. Conversely, the utilization of the maximum