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Use of textural measurements to map invasive wetland plants in the Hudson River National Estuarine Research Reserve with IKONOS satellite imagery

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ABSTRACT

At this point, models, and accompanying field data, that could be used to predict the likely response of estuaries and tidal marshes to future environmental change are lacking. To improve this situation, monitoring efforts in these complex ecosystems need to be intensified, and new, efficient monitoring techniques should be developed. In this context, our research assessed the use of IKONOS satellite imagery to map plant communities at Tivoli Bays, in the Hudson River National Estuarine Research Reserve (HRNERR). Tivoli Bays, a freshwater tidal wetland, contains a unique assemblage of plant communities, including three invasive plants (*Trapa natans*, *Phragmites australis*, and *Lythrum salicaria*). To study the effects of textural information on the accuracy of land cover maps produced for the HRNERR, seven different 11-class land cover maps were produced using a maximum-likelihood classification on seven combinations of spectral and textural data derived from an IKONOS image. Conventional contingency tables served as a basis for an accuracy assessment of these maps. The overall classification accuracies, as assessed by the contingency tables, ranged from 45% to 77.7%. The maximum-likelihood classification relying on four spectral and four 5-by-5 filter textural bands (created by superposing a textural filter separately on each band of the IKONOS image) had the lowest overall accuracy, whereas the one based on four spectral and four 3-by-3 filter textural bands associated with all segments, identified by an object-based classification of the IKONOS image, had the highest accuracy. Results suggest that a combination of per-pixel classification and incorporation of texture for segments generated through an object-based classification slightly increases classification accuracy from 76.2% for the maximum-likelihood classification of the four spectral bands of the IKONOS image to 77.7% for the combination of spectral and textural information produced for selected segments. Further analysis indicates that better results may be obtained by using other types of data within the segments and that the traditional approach to the selection of training and accuracy sites may negatively bias the results for a combination per-pixel and object-based classification.

1. Introduction

Even though a large amount of uncertainty continues to afflict model predictions of global environmental change, a consensus exists among scientists that rapid change is underway and that anthropic activities are significant contributors (IPCC, 2007; Stern, 2006). With the exception of possible feedback effects of soils (Baveye, 2007), processes responsible for global climate change are well enough understood to advocate much needed remediation strategies, such as the widely recommended shift away from fossil fuel. However, at local and regional levels the outlook is quite different. There, reliable predictions are still needed to develop strategies that will help ensure adaptation to changes, which may include an increase in average yearly temperature, a sea level rise in coastal areas, associated shifts in plant and animal populations, and other types of environmental pressures on ecosystems (Lambert & Stine, 2008; Rosenzweig & Solecki, 2001).

Estuaries and tidal marshes are vivid illustrations of complex ecosystems found at a regional level that, because of their location, would be directly affected by climate change (Kennedy, 1990; Kennedy et al., 2002; Scavia et al., 2002; Short & Neckles, 1999). In particular, any temperature change or change in temperature extremes could cause plant population shifts in the estuaries and marshes themselves, alter the

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spread of non-native species that are already established in U.S. estuaries, and change the rate of non-indigenous species proliferation (Bradley et al., 2009; Cohen & Carlton, 1998; Jarnevich & Stohlgren, 2009; Mooney & Hobbs, 2000; Ruiz et al., 2000; Sutherst & Bourne, 2009; Tausch, 2008; Thomas et al., 2004). Non-native species modify estuarine species composition and alter the physical and chemical characteristics of local habitats, thereby constituting a significant force of change that affects population, community, and ecosystem processes in estuaries (Benoit & Askins, 1999; Emery & Perry, 1996; Grosholz, 2002; McDonald et al., 1989; Randall, 1996; Ruiz et al., 1997; Templer et al., 1998).

Monitoring programs in estuarine habitats allow coastal managers to better devise and implement adaptive management programs aimed at limiting the impacts of climate change and preserving regionally distinct native biodiversity (Wasson et al., 2002; Williams & Grosholz, 2008; Williams et al., 2007). A comprehensive plant species monitoring program in an estuarine system, at an acceptable temporal frequency, using traditionally established protocols for field analysis and aerial photograph interpretation, can be extremely time consuming and labor intensive (Hu et al., 2003; Zharikov et al., 2005). Until a few years ago, available satellite imagery was inadequate as an alternative. Laba et al. (2004) show that the 30-meter spatial resolution available with Landsat Thematic Mapper (TM) imagery is not sufficient to discern small areas of invasive species along the Hudson River in New York State, and does not enable the identification of an invasive impact until the undesirable species has reached dominance.

Higher-resolution satellite imagery, now commercially available, has far greater potential than TM imagery for mapping invasive species. Many researchers have turned to the wealth of spectral information provided by hyperspectral sensors to map invasive plant species in wetlands (e.g., Andrew & Ustin, 2008; Hestir et al., 2008; Judd et al., 2007; Pengra et al., 2007). Laba et al. (2008) used QuickBird imagery to map plant communities and monitor invasive plants within the Hudson River National Estuarine Research Reserve (HRNERR). A maximum-likelihood classification was used to produce 20-class land cover maps for each of the four marshes within the HRNERR. Gilmore et al. (2008) and Ghioca-Robrecht et al. (2008) both used multi-temporal QuickBird imagery to map marsh communities. Recently, Lee and Yeh (2009) analyzed the efficacy of using SPOT, Landsat, and QuickBird imagery to monitor shifting wetland vegetation in Taiwan. Encouraging classification accuracies found by these various researchers confirm the high potential of high-resolution satellite imagery to map invasive plant species in estuarine environments. Even better accuracies might be obtained if one of a number of possible refinements of the classification method were adopted. Incorporation of texture of the plant species in the remotely-sensed images appears particularly suited in this context.

The texture of imaged features has been the subject of significant interest and is playing an increasingly important role in natural resource applications of image analysis (e.g., Treitz & Howarth, 2000; Franklin et al., 2001; Arzandeh & Wang, 2002; Dekker, 2003; Maillard, 2003; Puissant et al., 2005; Pearlstine et al., 2005; Gong et al., 2008; Ozdemir et al., 2008), in spite of a lack of consensus on a unique definition of the concept. In general, texture consists of visual patterns or spatial arrangements of pixels that may have statistical properties, structural properties, or both (Haralick, 1979; Krishnamoorthi & Seetharaman, 2007). Russ (1999) defines texture loosely as a descriptor of local brightness variation from pixel to pixel in a small neighborhood through an image.

To date, little attention has been devoted to the use of texture to augment the classification of invasive wetland plant species. Laba et al. (2007) showed that textural analysis of a QuickBird image of a marsh of the HRNERR, based on a combination of Principal Component Analysis (PCA) with Discrete Wavelet Transform (DWT), allowed discrimination among four vegetative community types present in the marsh. Arzandeh and Wang (2003) did a textural classification of Radarsat data to improve their change detection of *Phragmites* in southern Ontario. A systematic investigation of the use of various texture measures to map invasive plant species in estuarine environments still has to be carried out.

In this general context, this research assessed the extent to which the use of various texture measures affects the multispectral classification of plant community types in one of the HRNERR tidal wetlands previously mapped by Laba et al. (2008). The research used a single, late summer IKONOS image of the Tivoli Bays wetland, and a classification scheme developed by HRNERR staff. Texture was taken into account in six different ways. First, classical measures of local texture in moving, 3-by-3 and 5-by-5 pixel windows superimposed on the remotely-sensed image were used. Second, a novel approach, involving a variance-based, edge-preserving smoothing of the image, followed by separation of the resulting smoothed segments into regions in which texture was calculated, was also implemented. In each case, trained classification of the IKONOS image was carried out using a maximum-likelihood method, and the relative accuracy of the resulting classifications was assessed.

2. Methods

2.1. Study area, imagery, and field data

Tivoli Bays is a 697 hectare (ha) freshwater tidal marsh with a tidal range of 1.2 meters (m). It is located along the Hudson River in Dutchess County, New York, and is one of four component sites in the HRNERR (Fig. 1). The two large river coves that make up the marsh are surrounded by wooded clay bluffs and are partially isolated from the Hudson River by a railroad causeway. The predominant plant species are narrow-leaved cattail (*Typha angustifolia*), spatterdock (*Nuphar advena*), and pickerel-weed (*Pontederia cordata*). Three invasive plant species — purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and water chestnut (*Trapa natans)* — are present in both bays (Yozzo et al., 2005; Laba et al., 2008).

The IKONOS image used in this study was acquired on August 18, 2006 at 10:59 AM with 0% cloud cover. The image was acquired within a half hour of a high tide of 1.06 m occurring at 10:26 AM. The data were full 11-bit radiometric resolution and were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system, Zone 18 North, World Geodetic System 1984 (WGS84), with a locational error of 15 m (CE90).

Training data consisted of field data collected in August of 2006 and 2007, supplemented with observations made in July and August 2004 (Laba et al., 2008). These training data were obtained within the context of an eleven-class land cover classification scheme (Table 1). The classification scheme was developed by the HRNERR staff for management purposes, to distinguish between areas of different dominant vegetation, to be useful for resource inventories, and to enable interfacing with classification systems used by other organizations (Laba et al., 2008). The fact that some of the training data were obtained in July and others in August is inconsequential, given that they were collected by field biologists, able to correctly identify vegetation at different stages of growth. Furthermore, because 2006–2007 data were only supplemented with 2004 training sites that contained 90% to 100% of the dominant species or that wouldn't have changed because of site conditions (e.g., phragmites), a few years were unlikely to affect the classification of the training sites.

In order for the training data to accurately reflect the spectral complexity and variability in species composition within a class, efforts were made to: (a) have a statistically valid number of training pixels (2 to 10 times the number of input bands used in the classification); (b) distribute the training areas throughout the marsh; (c) stratify them within each community type, as suggested by Lachenbruch (1975), Swain and Davis (1978), Derde and Massart (1989); and (d) carefully select training sites to correctly represent each cover type and make concern over the locational error of the image unnecessary. Training data were not developed for railroad causeway and upland because they were not of interest to this study and a post-classification mask was applied to them.