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Balloon imagery verification of remotely sensed *Phragmites australis* expansion in an urban estuary of New Jersey, USA

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ABSTRACT

The invasion of the exotic common reed (*Phragmites australis*) is increasingly displacing local native species from northeastern coastal estuaries. This study evaluates the accuracy of a remote sensing technique to map the distribution of common reed, monitor the rate of invasion and determine areas of natural resistance to invasion. The current invasion footprint of *Phragmites* in the Hackensack Meadowlands District in Northern New Jersey was determined using high spectral and spatial resolution hyperspectral imagery. A tethered balloon-based imaging device with limited coverage area was used to assess the accuracy of the hyperspectral imagery classification. The accuracy assessment based on true color balloon images revealed that the hyperspectral classification technique from images covering hundreds of hectares was 90% accurate in separating the dominant common reed-invaded areas from the native vegetation. Furthermore, linear spectral un-mixing techniques for sub-pixel classification revealed that for mixed areas where *Phragmites* covered 75% or more of a pixel, the classification was correct 96% of the time. The accuracy dropped to 52% for pixels that contained 25% or less of *Phragmites* cover, and was only 4% for pixels where invasive and native species cover was the same (50–50%).

1. Introduction

The invasion of Eastern Shore and Gulf Coast Marshes by the introduced exotic genotype of common reed (*Phragmites australis* (Cav.) Trin. Ex Stuedel is strongly associated with extensive monocultures and reduced overall biological diversity (Windham and Lathorp, 1999; Able et al., 2003). The ability of this plant to displace native species by altering the local hydrology has created a range of vegetation mixture types along biogeochemical gradients (Bart and Hartman, 2000; Chambers et al., 1998). Dense *Phragmites* monoculture stands are 3–4 m tall and represent the end point of the invasion. Prior to reaching that stage, *Phragmites* and native grasses co-exist in mixtures depending on the degree of invasion. The remaining pure native grass relicts usually exist completely surrounded by *Phragmites* mixtures. The fact that these relicts persist over time may be explained by sediment biogeochemical gradients, as the native species are known to be more tolerant to anoxic and high sulfide conditions than *Phragmites* (Artigas and Yang, 2005; Chambers et al., 2003).

There is an increasing pressure to protect the remaining native species and its associated biodiversity (Ailstock et al., 2001). The Meadowlands District is part of the Atlantic flyway bird migration route that provides good sources of food water and cover and is in direct competition with pressure from developers seeking to develop light industrial warehouses and distribution centers near and with good access to Manhattan and New York City. Hence, there is a need for developing cost effective methodologies for accurately determining the health and extent of the remaining open areas specifically the spatial distribution of *Phragmites* and its associated mixtures types at the landscape level.

High spatial and spectral resolution imaging spectrometers mounted on fixed wing airplanes and measuring light reflectance in many wavelengths have successfully been used to discriminate marsh vegetation types and even vigor classes of the same species as they respond to biogeochemical sediment gradients (Artigas and Yang, 2005). These airborne sensors are able to map hundreds of hectares in just a few hours and the only difficulty occurs when species having similar external architecture and internal tissue morphology reflect light in similar ways and are indistinguishable from one another (Townshend et al., 2000; Okin et al., 2001). Fortunately, studies have shown that the spectral response of marsh grass populations and assemblages have unique spectral characteristics with the exception of species belonging to the same genus (i.e. *Spartina alterniflora* – saltmarsh cordgrass and *S. patens* – saltmeadow cordgrass) (Artigas and Yang, 2005). Plant mixtures can be a problem, but there are techniques that help discriminate the importance (%cover) of each species in a pixel.

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The linear un-mixing technique first introduced by Adams and Smith (1986) in differentiating dust from bare rock surfaces is a method that can also be used for revealing the spectral characteristic of mixed vegetation pixels by taking into account the pure vegetation spectra that originate from the mixture types (Adams et al., 1995; Bastin, 1997; Wang et al., 2007a).

In this study, we show that these sub-pixel techniques are useful in characterizing the mixture types at and near the invasion fronts but in order to extrapolate to larger areas require fine tuning using reliable and scale-appropriate ground reference areas.

Schmidt et al. (2004) reviewed different vegetation remote sensing mapping efforts and concluded that the limited number of areas verified on the ground, along with the spectral averaging of non homogenous areas (sub-pixel mixtures) are the main reasons for the low accuracy of these vegetation maps. Belluco et al. (2006) concludes, however, that extensive sets of field observations resulted in higher accuracy vegetation maps derived from remote sensing. The extent of the accuracy that can be obtained from these classifications is uncertain and will mostly depend on the quality and quantity of the ground validation points. Traditional field verification requires reaching hard to access areas over unconsolidated marsh surfaces. Moreover, when the vegetation is 3 m or higher, it is difficult, if not impossible, to detect canopy differences from the ground. A way to approach this problem is to have a perspective from above the canopy.

Digital cameras mounted on a tethered helium-balloon are becoming more frequent in agricultural crop management; they are used to monitor genetic resources and to estimate water consumption (Jia et al., 2004; Jensen et al., 2007; Oberthür et al., 2007; Wang et al., 2007b). Digital cameras flown side by side with hyperspectral sensors opened a new way in addressing remote sensing challenges. In addition, as they are flown at a lower altitude they bridge the spatial gap between radiometric measurements collected near the surface and those acquired by other aircraft or satellites (Vierling et al., 2006; Chen and Vierling, 2006).

Our objective was to use digital cameras from a tethered balloon to assess sub-pixel remote sensing classifications of marsh vegetation using a high spectral and spatial resolution spectrometer. We hypothesized that using high resolution balloon imagery for selecting training areas would improve the accuracy of the final vegetation map and provide a better tool for assessing *Phragmites* invasion.

2. Methods and materials

2.1. Study area

The New Jersey Meadowlands district is located in northeastern New Jersey, three miles west from the Upper New York Bay (Fig. 1). Decades of draining, ditching, filling and installation of dikes and tide gates have altered the lower reaches of the Hackensack River

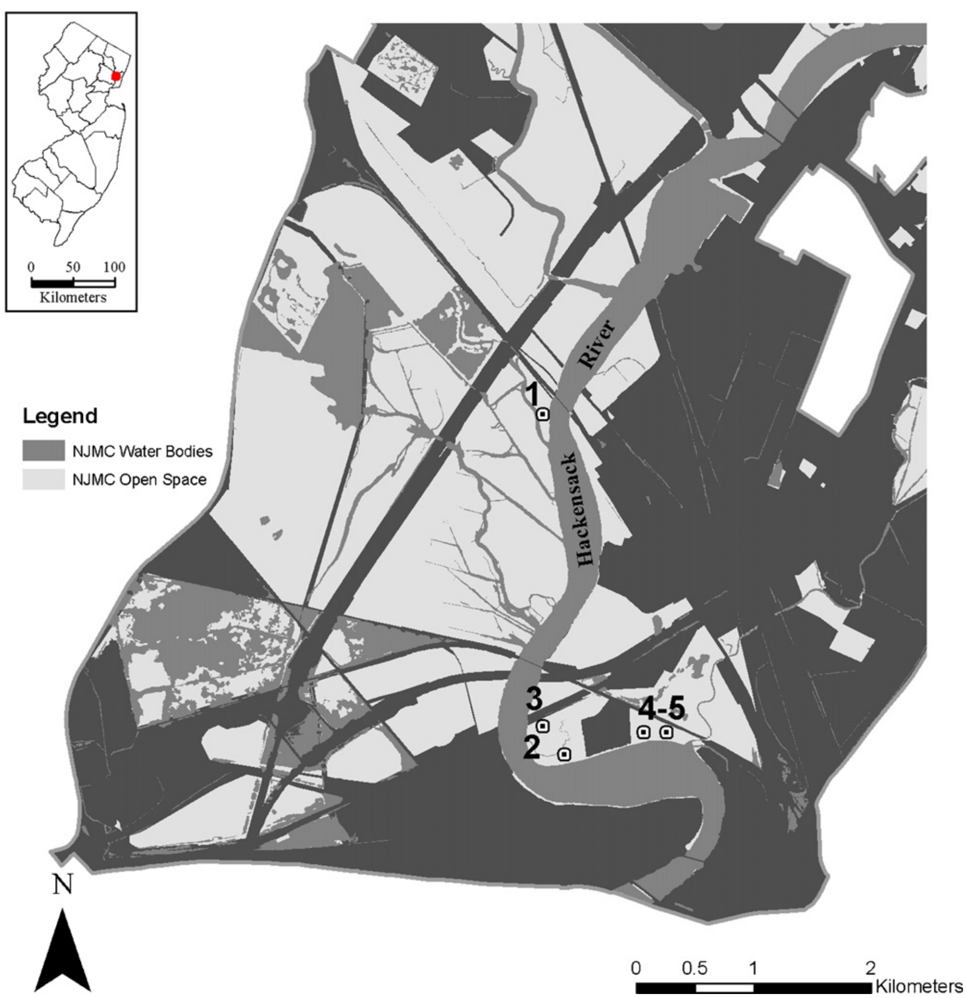

Fig. 1. Map of the New Jersey Meadowlands District showing the locations from where balloon images were captured to produce the training sites used to ground-truth the hyperspectral image: (1) Lyndhurst Marsh; (2 and 3) The Riverbend Wetland Preserve; (4 and 5) Fish Creek. Left upper coordinates: Lat.: N 40°27′13.13″; Long.: W 73°41′0.82″.