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Mapping invasive wetland plants in the Hudson River National Estuarine Research Reserve using quickbird satellite imagery

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Abstract

The National Estuarine Research Reserve (NERR) program is a nationally coordinated research and monitoring program that identifies and tracks changes in ecological resources of representative estuarine ecosystems and coastal watersheds. In recent years, attention has focused on using high spatial and spectral resolution satellite imagery to map and monitor wetland plant communities in the NERRs, particularly invasive plant species. The utility of this technology for that purpose has yet to be assessed in detail. To that end, a specific high spatial resolution satellite imagery, QuickBird, was used to map plant communities and monitor invasive plants within the Hudson River NERR (HRNERR). The HRNERR contains four diverse tidal wetlands (Stockport Flats, Tivoli Bays, Iona Island, and Piermont), each with unique water chemistry (i.e., brackish, oligotrophic and fresh) and, consequently, unique assemblages of plant communities, including three invasive plants (*Trapa natans*, *Phragmites australis*, and *Lythrum salicaria*). A maximum-likelihood classification was used to produce 20-class land cover maps for each of the four marshes within the HRNERR. Conventional contingency tables and a fuzzy set analysis served as a basis for an accuracy assessment of these maps. The overall accuracies, as assessed by the contingency tables, were 73.6%, 68.4%, 67.9%, and 64.9% for Tivoli Bays, Stockport Flats, Piermont, and Iona Island, respectively. Fuzzy assessment tables lead to higher estimates of map accuracies of 83%, 75%, 76%, and 76%, respectively. In general, the open water/tidal channel class was the most accurately mapped class and *Scirpus* sp. was the least accurately mapped. These encouraging accuracies suggest that high-resolution satellite imagery offers significant potential for the mapping of invasive plant species in estuarine environments.

Keywords: Estuarine; Nerr; Remote sensing; Tidal fresh-water wetland; Invasive species; Land cover mapping; Quickbird; Fuzzy assessment

1. Introduction

For hundreds of years, estuaries have been recognized as some of the most dynamic and productive environments. Transitional places where salt and fresh water mix, estuaries serve as nurseries for numerous commercial fish and shellfish species. They also act as rest stops for migratory birds, filters for pollution, and buffers against coastal erosion. The high value that society places on estuaries for living, working, transportation, and recreation, has made these habitats among the most densely populated around the world (Costanza et al., 1997).

In the 1960s and early 1970s, the public at large, and eventually a number of policy makers, became concerned by increasingly noticeable signs of estuarine degradation in the United States. Heightened awareness toward this problem resulted in the passage of legislations aimed at protecting estuarine ecosystems, in particular the landmark Coastal Zone

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Management Act of 1972, which led to the creation of the National Estuarine Research Reserve (NERR) System. The NERR system is dedicated to long-term research, monitoring, education, and resource stewardship. Its research focus is intended to guide national, regional, and local efforts toward the protection and conservation of estuarine habitats, through the provision of improved ecological information. Currently, 27 NERR reserves in 22 states and territories protect over 1.3 million acres of estuarine waters, wetlands and uplands (NOAA, 2006).

In 2006, the NERR system established research priorities that would enable the system to move forward in conducting and supporting research to improve basic understanding of the biological and ecological conditions found within estuarine systems and to characterize, monitor, and quantify change in these conditions. Focus areas include: habitat and ecosystem coastal processes, anthropogenic influences on estuaries, habitat conservation and restoration, species management, and social science and economics (NOAA, 2006). A major goal of the NERR Research and Monitoring plan (NOAA, 2006) is to develop a system-wide remote-sensing strategy that supports and enhances ongoing biological monitoring and habitat classification.

A key aspect of this strategy involves targeted monitoring of the occurrence and distribution of invasive species using remotely sensed data. The Pew Oceans Commission (Pew Oceans Commission, 2003) identified the presence of invasive species as one of the key pressures on estuaries. A recent survey of the NERRs indicates that the majority of reserves are impacted by biological invasions (NOAA, 2006). Hundreds of non-native aquatic species have become established in U.S. estuaries and the rate of non-indigenous species accumulation is apparently increasing at a fast pace (Cohen & Carlton, 1998; Ruiz et al., 2000). Non-native species alter estuarine species composition and potentially affect the behavior, distribution, and trophic interactions of native species. Some non-native species alter the physical and chemical characteristics of estuarine habitats as well, and thereby constitute a significant force of change affecting population, community, and ecosystem processes in estuaries (Grosholz, 2002; Malecki et al., 1993; McDonald et al., 1989; Randall, 1996; Ruiz et al., 1997). In particular, invasive plant species have been found to alter wetland decomposition rate and nutrient cycling, lead to reduction in wetland plant diversity, threaten rare and endangered plant and animal species, reduce pollination and seed output of native plants, as well as reduce habitat suitability for several wetland bird species including black terns, least bitterns, pied billed grebes, and marsh wrens (Benoit & Askins, 1999; Brown, 1999; Emery & Perry, 1996; Templer et al., 1998).

Whereas the environmental and economic damages caused by non-native species are now widely acknowledged (Carlton, 2001; Corn et al., 1999), experts concede that the patterns of invasion in U.S. estuaries remain confounded, and identify a vital need to initiate “standardized ecological surveys of non-native species across major regions of the U.S.” (Ruiz et al., 2000). In the past, monitoring invasive species in estuarine environments at a landscape scale has not been a top research priority. However, quantitative measurements that are standardized and repeated across multiple sites would be the most effective way to determine the factors that affect invasion success, the attributes of species that make them likely to invade and have negative impacts, and the characteristics of environments that make them resistant or vulnerable to invasion (Wasson et al., 2002). Monitoring would also facilitate early detection of new invasions, within the window of opportunity where eradication efforts may be successful. By simultaneously carrying out monitoring across estuaries for invaders and native species, along with physical and chemical characterization, NERR scientists could determine how ecological impacts vary geographically, and attempt to identify the mechanisms behind observed differences. An invasion monitoring program in estuarine habitats also allows coastal managers and resource agencies to better devise and implement effective strategies for preserving regionally distinct native biodiversity.

To carry out a comprehensive invasive plant species monitoring program in an estuarine system, at an acceptable temporal frequency, using traditionally established protocols for field analysis and aerial photograph interpretation, as was classically done in the past (Hu et al., 2003; Zalidis et al., 1997; Zharikov et al., 2005), requires extensive time and work. Until a few years ago, available satellite-based imagery was inadequate as an alternative. Laba et al. (2004) showed that the moderate spectral and spatial resolutions available with Thematic Mapper (TM) imagery were not sufficient to discern mixed community types or small areas of invasive species at the HRNERR, and did not enable the identification of an invasive impact until the undesirable species has reached dominance.

Fortunately, higher-resolution satellite-based imagery is now commercially available. QuickBird (2.4 m minimum mapping unit) and Ikonos (4 m minimum mapping unit) not only offer a higher spatial resolution image, but also offer the possibility of low-tide image acquisition at an economically viable cost, a feature that may prove particularly useful in estuarine environments. Both Ikonos (Wang et al., 2004a,b) and QuickBird (Rocchini et al., 2004, 2005; Tsai & Chou, 2006; Wang et al., 2004a,b; Wolter et al., 2005) have been used to map vegetation in a number of different wetland environments, including mangroves and submerged aquatic vegetation. However, the usefulness of high-resolution satellite imagery to map the spread of invasive plant species in a range of estuarine environments (salt to fresh) has yet to be assessed.

In this context, the key objective of this research effort is to describe such an assessment, carried out at the species level in the four separate marshes comprising the Hudson River National Estuarine Research Reserve (HRNERR) and representing a range of environments. In these marshes, purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and water chestnut (*Trapa natans*) are the primary invasives, with common reed posing the greatest threat. Specifically, we used a maximum-likelihood classifier to produce 20-class land cover maps for each of the four marshes within the HRNERR. Conventional contingency tables and a fuzzy set analysis served as a basis for an accuracy assessment for each of these maps.