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Characterizing patterns of plant distribution in a southern California salt marsh using remotely sensed topographic and hyperspectral data and local tidal fluctuations

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Abstract

We used LiDAR topographic data, AVIRIS hyperspectral data, and locally measured tidal fluctuations to characterize patterns of plant distribution within a southern California salt marsh (Carpinteria Salt Marsh (CSM)). LiDAR data required ground truthing and correction before they were suitable for use. Twenty to forty percent of the uncertainty associated with LiDAR was due to variance in the elevation of the target surface, the balance was attributed to error inherent in the LiDAR system. The incidence of LiDAR penetration of plant canopy cover (i.e., registration of ground elevation) was only three percent. The depth of LiDAR penetration into the plant canopy varied according to plant species composition; plant species-specific corrections significantly improved LiDAR accuracy (58% reduction in overall uncertainty) and with the use of ground-based surveys, reduced overall RMSE to an average of 6.3 cm in vegetated areas. A supervised classification of AVIRIS data was used to generate a vegetation map with six classification types; overall classification accuracy averaged 59% with a kappa coefficient of 0.40. The vegetation classification map was overlaid with a LiDAR-based digital elevation model (DEM) to compute elevation distributions and frequencies of tidal inundation. The average elevations of the dominant plant classifications found in CSM (e.g., *Salicornia virginica*, *Jaumea carnosa*, and salt-grass mix, a mixture of multiple marsh plant species) occurred within a 17 cm range, a vertical change that resulted in a 7% difference in the period of tidal inundation.

Keywords: LiDAR; AVIRIS; Tidal salt marsh; Tidal inundation

1. Introduction

There are a number of biotic, hydrologic and edaphic factors that govern the distribution of macrophytes within salt marshes. Numerous studies have investigated the mechanisms affecting plant distributions (e.g., Frenkel et al., 1981; Hinde, 1954; Marani et al., 2006; Odum, 1988; Pennings & Callaway, 1992; Silvestri et al., 2003, 2005; Ursino et al., 2004; Zedler, 1977; Zedler et al., 1999). Recent research has identified several different factors which influence zonation; Silvestri et al. (2005) provide a review of the historic development of hypotheses concerning patterns of zonation among salt marsh plants. Inter- and intra-specific competition, nutrient availability, soil moisture, porewater salinity, soil redox potential, sulfide concentration, and organic content of the soil all interact to influence the distribution of macrophytes (Mitsch & Gosselink, 2000).

The characteristic patterns of zonation seen in salt marsh macrophyte communities are frequently based in part on a vertical elevation gradient (Zedler et al., 1999). Consequently, tidal elevation is a convenient metric that integrates a number of hydrologic and edaphic factors. Although related to tidal elevation, frequency of tidal inundation describes more of the variability in salt marsh plant distributions than elevation alone (Bockelman et al., 2002). Frequency and duration of tidal inundation affect soil moisture and porewater salinity, which in turn influence soil redox potential, sulfide concentrations, and concentration of organic material (Zedler, 1999). Small

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differences in elevation (e.g., <5 cm) can result in significant differences in patterns of plant distribution (Callaway et al., 1990; Silvestri et al., 2003).

Studies evaluating distribution patterns of plants in salt marshes have typically determined elevation using traditional survey techniques along transects, from which corresponding vegetation patterns were determined (Hinde, 1954; Zedler 1999). Refinements in the use of remote sensing have enabled researchers to begin to characterize both marsh topography (Rosso et al., 2005) and the spatial distribution of plant classifications (Hirano et al., 2003) in detail at the whole marsh scale.

LiDAR (Light Detection and Ranging) is increasingly being used in studies of ecosystem processes (Lefsky et al., 2002). However, the usefulness of LiDAR for mapping ground surfaces is a function of the ability of the laser to penetrate the vegetation canopy. LiDAR has been used to good effect in forest systems (Lefsky et al., 2002) where canopy structure is open allowing frequent laser penetration to the ground and the distance between the bottom of the canopy and the ground is large relative to the thickness of the canopy. LiDAR has potential for use in systems with low, dense canopy structure as well, but its application is more problematic (Davenport et al., 2000; Rosso et al., 2005). Thick canopy structure reduces the probability of laser penetration to the ground and increases LiDAR error. For LiDAR to be useful in this context, the elevation range of ecological importance for a given study must exceed the uncertainty in elevation resulting from LiDAR.

LiDAR accuracy is normally reported by the vendor, but stated accuracies are frequently obtainable only under ideal conditions and error analysis typically lacks the level of rigor necessary for scientific study (Hodgson & Bresnahan, 2004). Error assessment is commonly done using surface types that are convenient to measure (e.g., streets or airport tarmac) but may not reflect error associated with surface types relevant to ecological studies (Hodgson & Bresnahan, 2004). More studies that evaluate error from ecologically relevant surfaces are needed, especially in systems that are dominated by low, closed canopy vegetation. The need for careful error assessment of LiDAR is compounded when its application is in systems where small changes in elevation have significant ecological effects.

Hyperspectral imagery from imaging spectrometers (e.g., Airborne Visible and Infrared Imaging Spectrometer (AVIRIS)) has been applied to salt marshes. By using a large number of contiguous bands, hyperspectral data characterize important diagnostic signatures in reflectance, establishing a basis for plant species identification (Hirano et al., 2003). Hyperspectral data have been used to map and determine plant cover in salt marshes (Belluco et al., 2006; Donoghue et al., 1994; Li et al., 2005; Marani et al., 2006; Rogers and Kearney, 2004; Silvestri et al., 2003; Thomson et al., 2004), to map the spread of invasive plant species (Rosso et al., 2005), and, combined with elevation data for marsh plants, to create digital elevation maps of salt marsh areas (Silvestri et al., 2003). While recent improvements in classification techniques have been made (e.g., see Silvestri et al., 2002 for a description), the use of hyperspectral imaging in salt marshes is not without challenge. Salt marsh plant communities can be highly heterogeneous at a small spatial scale and the relationship between heterogeneity and pixel size makes selection of the appropriate endmembers critical to the accuracy of a final vegetation classification. Belluco et al. (2006) provide a discussion of the relative importance of spectral and spatial resolution for identification of marsh plant species.

Our objective was to use remote sensing data in a southern California salt marsh to characterize patterns of marsh plant distribution at the whole marsh scale. An integral part was an evaluation of the accuracy of LiDAR for use in describing distribution patterns that can vary on a small vertical scale. The focus of our study was on the use of LiDAR in a closed canopy marsh. We used well established AVIRIS hyperspectral classification methods to evaluate patterns of plant distribution. We expected plant distribution to be influenced by the interaction between elevation and tidal hydrology (i.e., inundation). To test this hypothesis we measured tidal stage within Carpinteria Salt Marsh (CSM) and developed an inundation-elevation regression model for the marsh. We used a LiDAR-based digital elevation map (DEM) of the marsh in conjunction with the inundation model to characterize spatial patterns of inundation. Finally, plant classification data derived from AVIRIS were mapped onto the DEM to characterize the distribution of plants with relation to elevation and inundation.

2. Methods

2.1. Site description

Our study was conducted in Carpinteria Salt Marsh, a 93 ha estuarine tidal wetland located 12 km east of Santa Barbara, California (34°24′N, 119°31′W). The marsh is divided into three main basins: basin 1 is located at the eastern end of the marsh and is bounded by two tidally influenced channelized creek beds with little or no connectivity to the marsh plain; basin 2, located in the middle of the marsh, is bounded by a channelized creek bed on the east and an unpaved road on the west and has restricted tidal connectivity; basin 3, the western portion of the marsh, has the most complex network of tidal channels and unrestricted tidal connectivity. The majority of freshwater input into the marsh is through two creeks that enter in the northeast corner; although there are a number of smaller freshwater drainages along the northern marsh boundary. The tidal inlet to the marsh, which opens to the Santa Barbara Channel, is stabilized by rock revetments. In 2005 a channel was dredged through a cobble sill located near the mouth of the marsh as part of a restoration effort designed to increase tidal range and tidal prism. *Salicornia virginica* is the dominant macrophyte among the assortment of salt marsh plants common to southern California estuaries. More detailed descriptions of the physical and biological features of the marsh are given by Callaway et al. (1990), Page et al. (1995) and Hubbard (1996).

2.2. Collection of LiDAR and survey elevation data

We used LiDAR data for Carpinteria Salt Marsh collected in 2003 by a commercial vendor (Airborne 1, www.airborne1.com). They used an ALTM 1225 sensor mounted on a fixed wing