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Classification of salt marsh vegetation using edaphic and remote sensing-derived variables

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ABSTRACT

Salt marsh plant communities are known for their striking patterns of vertical zonation. Two of the most important edaphic parameters that affect species distribution patterns are soil salinity and waterlogging, both of which are related to topographical variations and distance to the water. The primary objective of this study was to evaluate whether information on elevation and distance derived through remote sensing could be used to predict plant distributions in a southeastern United States salt marsh. We classified four marsh vegetation classes (tall *Spartina alterniflora*, medium *S. alterniflora*/short *S. alterniflora*, marsh meadow, and *Borrichia frutescens*/*Juncus roemerianus*) based on landscape metrics obtained from a light detection and ranging (LIDAR)-derived digital elevation model (DEM) and compared results to a classification based on field-collected edaphic variables. Our secondary objective was to compare the performance of linear discriminant analysis (LDA) with non-parametric classification and regression trees (CART) for these classifications. Models based on the edaphic variables soil water content, salinity, and redox potential attained accuracies of 0.62 and 0.71 with LDA and CART, respectively. When the remote sensing-derived variables DEM elevation, slope, distance to the mean high water line, and distance to upland area were used, classification accuracies improved to 0.78 for LDA and 0.79 for CART. Our results suggest that remote sensing-derived metrics can capture edaphic gradients effectively, which makes them especially suited to landscape level analyses of salt marsh plant habitats, with potential application for predicting the effects of sea level rise on salt marsh plant distribution.

1. Introduction

Describing plant distributions in salt marshes is a topic of both basic and applied interest. Plant ecologists seek to understand the underlying mechanisms and the interactions between biological and physical factors that result in the characteristic zonation patterns found in salt marshes. Understanding plant distribution is also important for both habitat protection and restoration, particularly given the fact that ecosystem properties such as productivity, carbon sequestration and nutrient retention all vary with vegetation (Craft et al., 2009; McLeod et al., 2011). Finally, information on zonation is necessary for predicting how marshes will be altered by sea level rise, as landward transgression and changes in flooding patterns will result in shifts in species distributions (Warren and Niering, 1993; Gedan and Bertness, 2009; Wieski et al., 2010).

Salt marsh zonation is typically described in terms of elevation relative to the tidal frame, and can be used to separate the marsh into low, mid and high marsh zones based on flooding frequency. Marsh plant distribution along the gradient from low to high marsh is generally explained by the stress-to-competition hypothesis: different species perform best in different portions of the marsh, and are generally restricted at low elevations due to physiological tolerances and at high elevations by competition (Vince and Snow, 1984; Pennings et al., 2005). Although biological interactions can influence where particular plants are found (Callaway and Pennings, 2000; Pennings et al., 2005), salt marsh plant distribution has been largely attributed to varying plant physiological tolerances for salinity and flooding (Adam, 1990; Pennings et al., 2005), both of which are related to the extent and frequency of tidal inundation (Adams, 1963; Bockelmann et al., 2002). As a consequence, many investigators have used salinity and flooding, along with other edaphic parameters, to predict plant distributions (Rogel et al., 2000; Cacador et al., 2007; Batriu et al., 2011). An alternative to field measurements of edaphic parameters is to use elevation and distance metrics as proxies for inundation frequency and duration (Adams, 1963; Earle and Kershaw, 1989; Deleeuw et al., 1991). Elevation is often correlated with soil salinity and flooding (Adams, 1963; Adam, 1990; Sanderson et al., 2001), as well

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as other edaphic parameters that can affect plants, including oxygen availability (Chapman, 1974; Patterson and Mendelssohn, 1991), soil redox potential (Delaune et al., 1983; Pezeshki, 2001), nutrient availability (Gallagher, 1975), organic matter content (Morris and Haskin, 1990), and sulfide concentration (Mendelssohn and Morris, 2000). The distances to the mean high water (MHW) line and other tidal elevations indicate position within the marsh and the direction of tidal flooding, and are similarly related to flooding and salinity gradients (Ranwell, 1972; Sanchez et al., 1996). Elevation and distance to the MHW line have both been shown to be related to plant distribution (Earle and Kershaw, 1989; Zedler et al., 1999; Silvestri et al., 2005) and productivity (Mendelssohn and Morris, 2000; Morris et al., 2002) in salt marshes.

Remote sensing provides an alternative method for extracting elevation and distance metrics over broad spatial and temporal scales, allowing for ecosystem-wide habitat assessments at many points in time. It can also capture areas that may be difficult to access on the ground. Digital elevation models (DEMs) derived from light detection and ranging (LIDAR) have been used in conjunction with GIS to derive landscape metrics that can be used to predict plant distributions. In one of the most successful applications of this approach, Sanderson et al. (2001) quantified the influence of tidal channels by combining distance to channel and channel size to predict the probability of salt marsh species presence with 90% accuracy. Other landscape metrics, such as slope and distance to upland area (Sellars and Jolls, 2007; Andrew and Ustin, 2009; Griffin et al., 2011), have also been included in some analyses. Although simple correlations of elevation and/or distance metrics alone have been unable to fully explain plant zonation in salt marshes (Zedler et al., 1999; Silvestri et al., 2005), many investigators have successfully used elevation in combination with field measurements of edaphic variables (Woerner and Hackney, 1997; Byrd and Kelly, 2006; Lang et al., 2010; Suchrow and Jensen, 2010). However, no prior studies have examined the effectiveness of landscape variables such as elevation and distance metrics for predicting plant zonation in comparison to edaphic variables from the same study site.

Two parametric approaches commonly used to both explain and predict plant distributions are linear discriminant analysis (LDA) and logistic regression. LDA use *a priori* knowledge of existing class membership to separate groups based on linear or quadratic combinations of predictor variables. Even though observations do not necessarily have a linear response along ecological gradients (Austin, 2007; Suchrow and Jensen, 2010), LDA has been successfully applied in studies of vegetation zonation in both South Atlantic marshes (Sanchez et al., 1998; Isacch et al., 2006) and Southeastern U.S. salt marshes (Woerner and Hackney, 1997), with classification accuracies ranging from 57 to 70%. When data do not meet LDA assumptions (namely multivariate normality and homogeneity of variances), binary logistic regressions have been used to determine species presence or absence as a function of multiple variables. Logistic regression has been used to predict salt marsh species presence/absence using elevation, edaphic data and landscape metrics with limited success and is not considered further here (Zedler et al., 1999; Sellars and Jolls, 2007; Moffett et al., 2010).

Classification and regression trees (CART) represent a nonparametric method that is increasingly used as an alternative to LDA for the description and prediction of plant patterns using environmental data. Tree-based classification methods are valuable data exploration tools that provide straightforward visualization of the data structure through binary classification (categorical) or regression (continuous) trees. CART has numerous advantages over parametric methods: data do not need to be normally distributed or transformed, homogeneity of covariances is not assumed, missing data and combinations of categorical and continuous variables are permitted, hierarchical and non-linear relationships are captured, as are interactions between explanatory variables, and the method is robust to outliers (Breiman et al., 1984; De'ath and Fabricius, 2000). In salt marshes, CART has been used with accuracies that ranged from 54% to 90%. In California marshes, CART has been used for the differentiation of vegetation in relation to changes in upland sedimentation (Byrd and Kelly, 2006) and for modeling invasive species habitat near the marsh-upland border (Andrew and Ustin, 2009). CART has also been used to separate salt marsh vegetation in Australia using landscape position (Dale et al., 2007) and in the Lagoon of Venice using edaphic variables (Lang et al., 2010).

It has been suggested that CART can be used as a tool to reduce the number of variables used to train a parametric classifier such as LDA (Breiman et al., 1984; De'ath 2007; Maindonald and Braun, 2007); however, we have found no examples of this suggested workflow. Additionally, although the utility of CART has been compared to linear models in other ecosystems (De'ath and Fabricius, 2000; Vayssieres et al., 2000), CART and LDA have not been directly compared in a salt marsh.

The primary objective of this research was to evaluate the robustness of remote sensing data as an alternative to the use of edaphic data for predicting salt marsh vegetation patterns and representing underlying environmental gradients. Our secondary objective was to directly compare LDA and CART. Our results provide support for the use of remote sensing data for assessing vegetation patterns as an effective alternative to the use of edaphic data.

2. Methods

2.1. Study site

This study was located in the salt marshes in and around Sapelo and Blackbeard Islands, Georgia, USA (UTM Zone 17 N, 471480 E 3473972 N, Fig. 1), and included 23 km^2 of salt marshes. The site is located in the Georgia Coastal Ecosystems Long Term Ecological Research domain and the Sapelo Island National Estuarine Research Reserve. Tides are semi-diurnal with a mean tide range of 2.5 m in this area. *Spartina alterniflora* is the dominant macrophyte in these marshes, covering over 80% of the total area (Hladik et al. 2013). *S. alterniflora* can grow up to 2 m tall and is the primary plant found along the regularly-flooded creek banks in the low marsh. Although plant height represents a continuum, medium height *S. alterniflora* (approximately 0.5–1.0 m) dominates the mid-marsh and shorter plants (<0.5 m) are found in the irregularly flooded high marsh. The high marsh contains a mixed marsh meadow community (*Salicornia virginica (more recently reclassified as as Sarcocornia sp., USDA, 2010), Batis maritima, Distichlis spicata* and short *S. alterniflora*). At the highest elevations, *Juncus roemerianus* and *Borrichia frutescens* become the dominant species.

2.2. Field variables

Plant characteristics and edaphic variables were measured at 369 locations throughout the Duplin River ($N = 217$) and neighboring Blackbeard Island ($N = 152$) salt marshes in February 2010 for eight vegetation cover classes: *Spartina alterniflora* (short, medium, and tall height classes), *Juncus roemerianus*, *Batis maritima*, *Distichlis spicata*, *Salicornia virginica*, and *Borrichia frutescens*. Sampling locations were randomly selected using the ArcGIS 9.3 software program and a hyperspectral vegetation classification of the salt marshes (Hladik et al. 2013). The number of points sampled per cover class ranged from 10 (*D. spicata*) to 88 (medium *S. alterniflora*) due to the relative dominance of the various habitat classes in the marsh (Fig. 1).