Spectral discrimination of marsh plant types in the New Jersey Meadowlands

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Introduction

Salt marshes are tidal wetlands that exist in coastal areas and are dominated by a few species of salt-tolerant grasses. In marsh ecosystems, monitoring and discriminating among vegetation covers types and the associated bare sediments are critical to understanding population distributions, biogeochemical functioning and the process of marsh recovery from disturbance. In traditional remote sensing, mapping vegetation types is challenging because plant canopies are usually smaller than the spatial extent of image pixels and the associated bare ground fractions and sediments may vary considerably in space and time (Price 1991; Chen et al, 1998; Okin et al. 2001). Hyperspectral sensors are becoming increasingly popular for vegetation mapping because of their high spectral resolution which allows for linkages between ecological or biophysical properties and electromagnetic fluxes at many different wavelengths. Spectral Mixture Analysis (SMA) is an emerging strategy in remote sensing to organize and transform raw images into variables related to ecological biophysical processes (Ustin et al. 1993, Gillepsi 1990, Roberts et al. 1990). In addition, the increased spatial resolutions of up to 1 m, where functional plant canopies are most likely to be larger than the spatial extent of image pixels, drastically reduces the mixed pixel problem where a pixel can have more than one surface type represented. It is well known however, that spectral signatures are not unique to plant types. The overlap in spectral signatures is common among species and even between foliages of the same species depending on the season, plant architecture and illumination angle (Knipling 1970; Price 1992; Cochrane 2000). The northeastern coastal marsh ecosystem is a good model to look at ecosystem biophysical functions and to attempt discrimination among species for several reasons: marsh grasses tend to form large monotypic stands, the number of species is relatively low (four or five vascular dominant species), the canopy is flat and even compared to desert shrubs or temperate or tropical forests and the disturbance prone nature of the marsh ecosystem creates physiognomic types that exist along salinity and oxygen gradients that may be detected using hyper spectral sensors.

The objective of this work is to investigate if marsh plant reflectance types are sufficiently different to constitute unique and separate members that could later on be combined using spectral mixing analysis to detect plant physiognomic types along environmental gradients at the landscape level. This study is a first exploratory step in addressing the greater question of physiognomic types along environmental gradients. To accomplish this first step, the medians of reflectance from the dominant marsh species present in our study area were compared using a set of statistical and similarity metrics to determine their similarities and differences at each wavelength in the visible and near infra-red.

Methods

The Meadowlands District, located just three miles west of Manhattan in northeastern New Jersey has a highly developed mixture of residential and industrial land uses interspersed among expanses of landfills, marsh grass fields, tidal wetlands and creeks, mudflats and rivers, all within one of the most developed and densely populated regions of the United States (Figure 1)

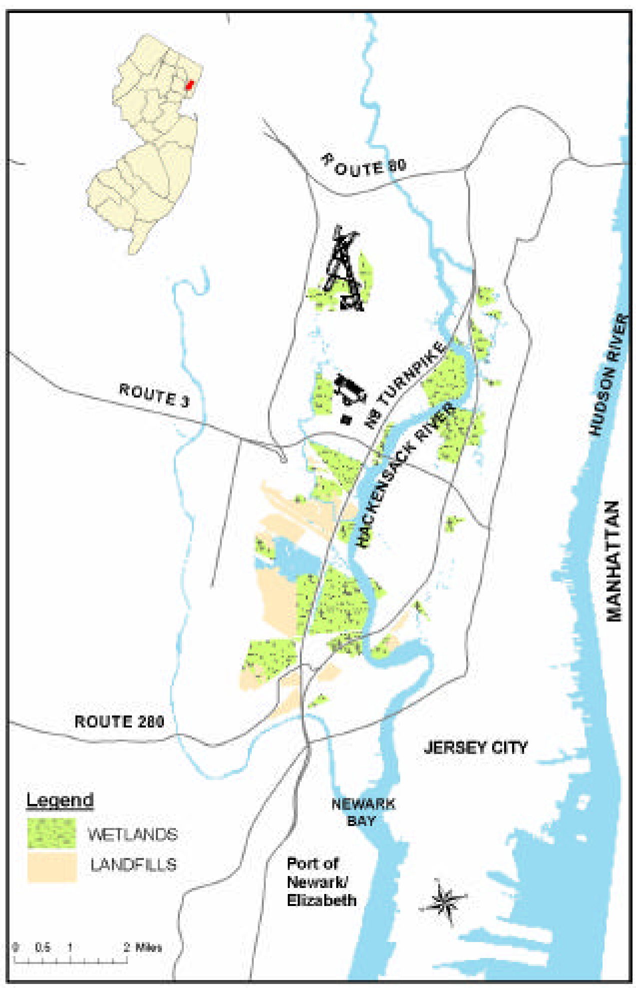


Figure 1. The maps show the remaining wetlands in the Meadowlands District of New Jersey. Reflectance measurements for the four dominant species were collected from 7 different sites.

The ditching and deposition of dredge spoils on the marsh surface during the 1920's and the removal of dikes in the 1950's along with storms and flooding have created and influenced the current environmental gradients within the marsh.

The most common wetland species occurring in pure stands are *Phragmites australis, Spartina alternifolia, Spartina patens and Distichlis spicata*. Seven sampling locations that contained pure stands of the dominant species were selected from aerial photographs. At each location, 10 m by 10 m quadrants were laid out and reflectance measured at four or five different points within the quadrant. One spectra was calculated as the median of 24 observations. The number of spectra collected was as follows: *Phragmites australis* 16; *Spartina alternifolia* 23; *Spartina patens* 12 and *Distichlis spicata* 13.

A FieldSpec ® Full Range spectroradiometer from Analytical Spectral Devices was used to collect plant reflectance measurements in the field. Reflectance data was recorded in the range from 350-1050 nm at an interval of 1.4 nm. The spectroradiometer was configured with an 8º field-of-view (FOV) lens giving an approximate 0.25 m diameter ground FOV from a height of 1.5 m from the target. Spectra measurements were made in the field under clear skies and within 1.5 hours of high sun. To ensure calibration accuracy, measurements were referenced to a Spectralon ® white reference panel both before and after each sampling period. Spectral data was recorded as apparent reflectance values (ASD 1997), plotted to verify any inconsistencies and cropped to a range of 350 to 950 nm.

The non-parametric Mann-Whitney U-test for comparison of medians (NCSR 1996) was used to test if significant differences exist between the medians of the apparent reflectance for each measured channel between all species pair combinations. The null hypothesis in this case is:

$$Ho: hspecies1(i) = hspecies2(i)$$

where species 1 and species 2 are compared at wavelength i. The statistical analyses identified, wavebands between 350 and 950 nm where the apparent reflectance between pairs were significantly different at P=0.001 (Figure 2, a,b,c,d,e,f).

The discrimination metrics D (Price 1994, Cochrane 2000) was computed to measure the similarity in the spectral response of the different species tested. For this purpose:

$$D = \left[\frac{1}{N-1} \sum_{i=1}^{N} [Sa(l) - Sb(l)]^2 \right]^{1/2}$$

where D is a root mean square difference between two spectra averaged over the spectral interval of observation N (350-950) with Sa and Sb being species a and species b and ?i, the wavelength being compared. The D value for each species pair was calculated and is presented in Figure 3.

Finally, the red–edge first derivative of the reflectance between 680 and 750 nm was measured according to Dabson et al. (1992) using the first order difference has an approximation of the differential in each spectral waveband:

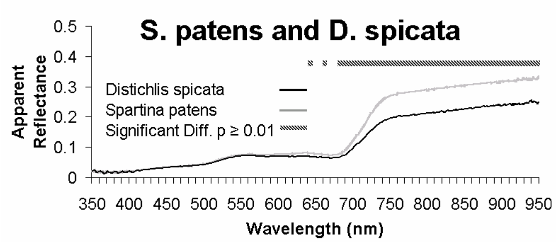
$$\frac{dS_1}{dl} = \frac{S_{i+1} - S_i}{l_{i+1} - l_i}$$

where S is the reflectance and λI is the wavelength of waveband i. After calculating the derivatives, the maximum slope value at each wavelength was computed for each species (Figure 4).

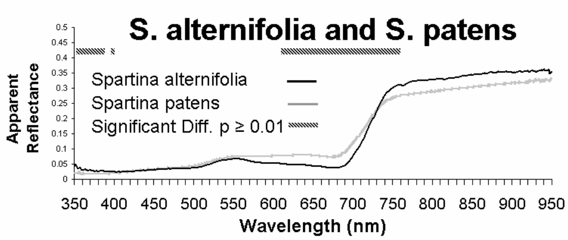
Results

<u>Mann-Whitney U-test for comparison of medians</u>

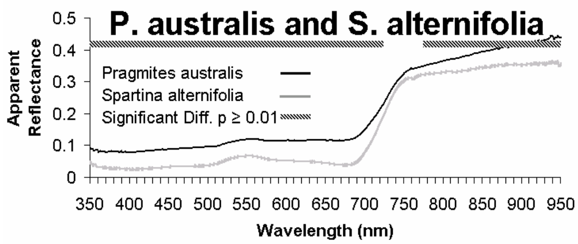
Figure 2, shows the reflectance in the visible and near infrared for the dominant marsh species. There is no significant difference between the high marsh species *Spartina patens* and *Distichlis spicata* in the visible (2,b). The *Spartina* species are significantly different in the orange and red segments of the spectrum (2,a). The apparent reflection of *Phragmites australis* (an invasive species) is significantly different from the two high marsh species *S. patens* and *D. spicata* (2c and d), and also different from *S. alternifolia* in most of the visible (2f). There is only a narrow segment between 640 and 660 nm where the two high marsh species are different (Figure 2b). *Spartina alternifolia* (low marsh species) and *D. Spicata* (high marsh species) have only a few narrow wavebands between 670 and 690 where they are different (Figure 2e). All species pairs have significantly different spectral response in the NIR with the exception *S. alternifolia* and *S. patens* (Figure 2a).

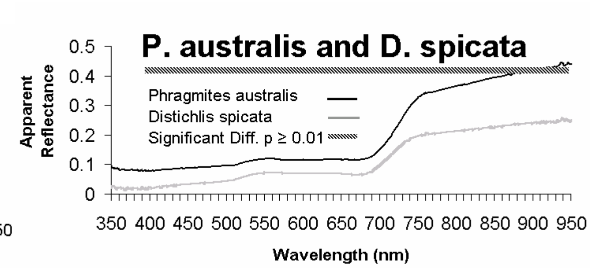


(a)

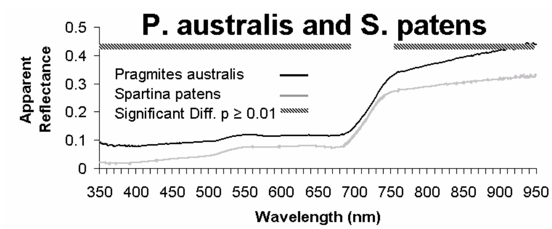


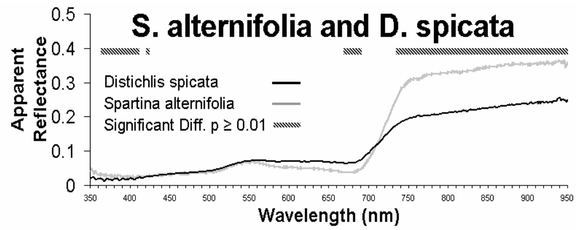
(b)





(c) (d)





(e) (f)

Figure 2. The graphs compare the apparent reflectance between the dominant marsh species. The Y-axis is apparent reflectance and the X-axis is wavelength in nanometers. The line of significant differences indicates that the medians of reflectance are significantly different at those wavelengths at p≥0.001.

<u>Discrimination metrics D</u>

The mean root square difference between reflectance in the visible and near infrared is shown in Figure 3. The most similar curves are those of *Spartina patens* and *Spartina alternifolia* (D=2.79). The most different curves are those of *Phragmites australis* and *Distichlis spicata* (D=10.75). The difference between high marsh species (D=4.75) is less than the difference between high marsh species and the invasive species *Phragmites australis* (D=6.5 and 10.75)

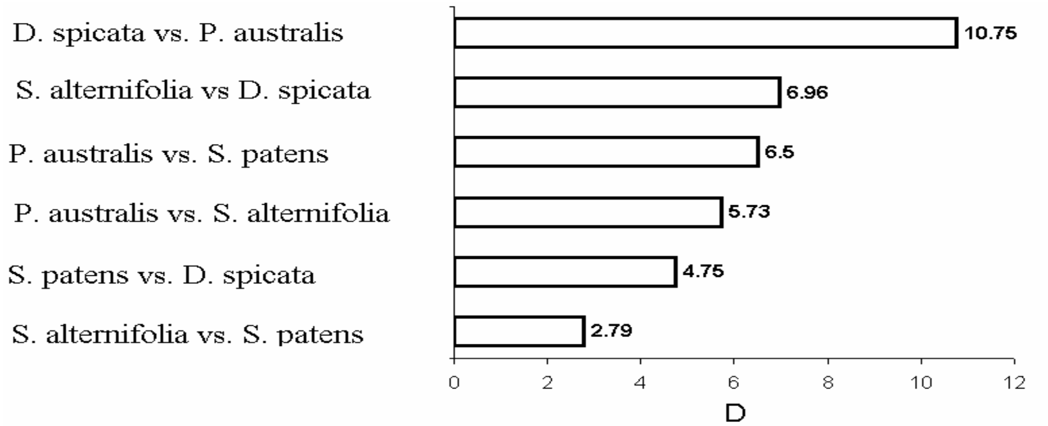
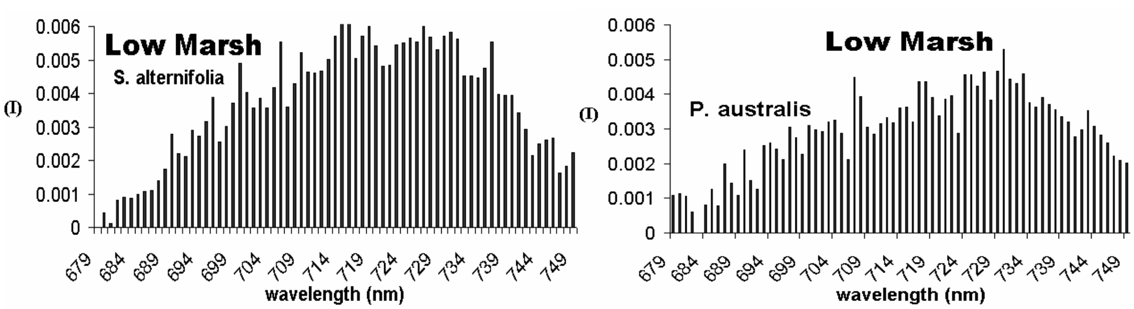


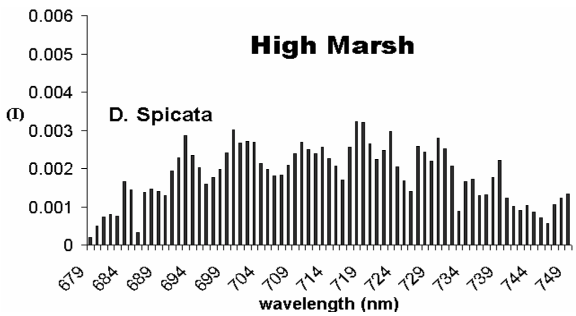
Figure 3. Root-mean square difference (D) between marsh surface spectra types averaged over the spectral interval of observation (350—950 nm).

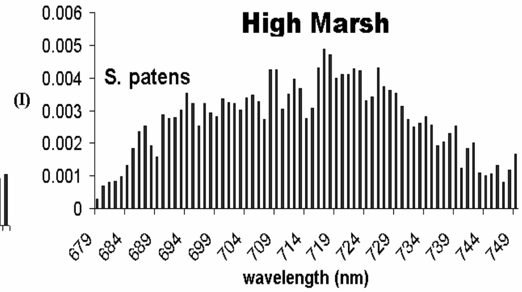
Red–edge first derivative

The distribution of the red edge inflections points between 640 and 750 nm are shown on Figure 4. The graph shows the inflection value (red-edge derivative) at each waveband. It can be noticed that *S. patens* shows a normal distribution (4a). Both *Phragmites australis* and *Spartina alternifolia* are skewed to the left (4c and 4d) and the distribution of *Distichlis spicata* is flatter and seemingly normal (4b). The maximum inflection point for phragmites australis occurred at 731 nm compared to *Spartina alternifolia* at 715 nm, *Spartina patens* at 717 nm and *Distichlis spicata* at 718 nm. The mean slope across the red edge (680-750 nm) shows that overall *Phragmites australis* has the steepest red-edge slope (0.26), followed by *Spartina alternifolia* (0.20), *Spartina patens* (0.19) and *Distichlis spicata* (0.13).



(a) (b)





(c) (d)

Figure 4. Red edge distribution of the maximum inflection value (I) for the various species

Discussion

There are several factors controlling the spectral response from marsh plants. First, there is the seasonal effect; as plants change colors with the season so does the way they reflect light. Our field observations show that to the human eye, marsh vegetation types are most distinct during early fall. Measurements made during this study are early fall measurements and may not apply to other seasons. Another factor influencing the spectral response is the amount of healthy photosynthetic tissue that translates into overall plant vigor in the marsh. Plants show differences in vigor according to their location along salinity and oxygen gradients (Redfield 1972). The stunted forms of *Spartina alternifolia* and *Phragmites australis* tend to occur at the higher extremes of the salinity gradient where they show less vigor and low density of stems compared to stands of the same species located at the lower range of the salinity-oxygen gradient where they form high density stands of vigorous green healthy looking plants. Measurements reported in this study were made from healthy stands, which account for 40 to 60% of the vegetated surface. A new field campaign is being planned to address the issue of the different ecotypes by sampling along a salinity-oxygen gradient. As a first step however, it was important to determine if the dominant species under the most favorable conditions are in fact spectrally different.

Results show that the most similar species in terms of their spectra are the high marsh *Spartina patens* and low marsh *Spartina alternifolia*. To the naked eye however, they look very different; *S. alternifolia* is a relatively tall and strait growing grass compared to *S. patens*, which is short and low lying. The spectral curves of these two species when compared statistically are very similar (Figure 2a) and the mean root square difference is the lowest among all species pairs compared (Figure 3). Moreover, red-edge mean slopes are similar (0.20 and 0.19) and the wavelength of maximum inflection is also similar (715 and 117 nm). Results also show that the best wavelengths to separate these two species -under fall conditions- is in the vicinity of the yellow-red absorption segment (i.e. 600 to 680 nm). The spectral similarity of these two species who belong to the same genus is not surprising since it is well known that the internal cell structure of leaves, which is genetically determined, influences the way light is absorbed, transmitted and reflected (Gates et al. 1965). It's interesting to note that the most similar species in terms of reflectance in effect occupy the two extremes of the elevation gradient (i.e. *S. alternifolia* low marsh, and *S. patens* high marsh)

The similarity index D (Figure 3) shows that the most distinct species were *Phragmites australis* and *Distichlis spicata.* The first one, is an invasive species that prefers well-drained soils at higher elevations and moderate salinity concentrations. Similarly, *Distichlis spicata* is a high marsh species also favoring higher elevations (Hellings and Gallagher 1992). The fact that these two species are spectrally very distinct is meaningful since it would, in theory, facilitate the identification of high marsh invasion fronts where both species are competing for the same space. Besides the *Spartina* species, which are statistically the same in the NIR, all other pairs are significantly different in the NIR. In the visible, there is a window in the spectrum (yellow-orange) where the reflectance of all species have wavebands were the reflectance is statistically different from each other.

Red edge first derivatives contain potentially useful information to discriminate among the species being considered. The frequency distributions of inflection values are quite different between the high marsh species and the invasive *Phragmites* and low marsh *Spartina alternifolia* (Figure 4) . High marsh species have near normal distributions while the other two are clearly skewed to the left. The invasive species *Phragmites australis* stands out with the greatest mean red-edge slope between 650 and 750 nm.

Conclusions

The study shows that healthy stands of the dominant species are distinct between each other at different wavelengths in the visible and NIR. The most problematic species to separate in the visible are the *Spartina* species. The dominant high marsh species *Distichlis spicata* and *Spartina patens* are also similar in the visible and this is compounded by the fact that they tend to form mixed stands. In this particular case, the possibility of a faulty classification is relatively high and when in doubt they should be considered as one member. The next step is to look at the different plant ecotypes and sediment substrate combinations to see if specific spectra or combinations of spectra are useful to classify marsh vegetation along salinity and oxygen gradients using images from an hyperspectral sensors

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