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NDVI as an indicator for changes in water availability to woody vegetation

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ABSTRACT

Barrier islands shrub thickets, the dominant woody community of many Atlantic coast barrier islands, are very sensitive to changes in the freshwater lens and thus, constitute a strong indicator of summer drought. NDVI was computed from airborne images and multispectral images on Hog Island (VA, USA) to evaluate summer growing season changes in woody communities for better predictions of climate change effects. Patterns of NDVI were compared year to year and monthly relative to precipitation and water table depth at the appropriate temporal scale. The highest absolute values of NDVI as well as the larger surface covered by woody vegetation (NDVI > 0.5) occurred in the wet year (2004) with a bimodal distribution of NDVI values (around 0.65 and 0.9) while both dry years (2007 and 2008) showed similar values in maximum, mean and standard deviation and unimodal distributions (around 0.75) of NDVI values. Positive linear adjustments were obtained between maximum ($r^2 > 0.9$) and mean NDVI ($r^2 > 0.87$) and the accumulated rainfall in the hydrological year and the mean water table depth from the last rainfall event till the date of the image acquisition. The spatial variations revealed that water table depth behaved different in wet and dry years. In dry years there was a remarkable increase in mean and maximum values linearly related to water table depth. The highest slope of the adjustment in 2007 indicated a sharp response of vegetation in the driest year. Monthly series of NDVI showed the major role of lack of precipitation through July and August in 2007 with missing classes of NDVI above 0.8 and unimodal distributions in mid-late summer. Best linear fits (r^2 close to 1) were obtained with rainfall at different temporal scales: accumulated rainfall in the hydrological year 2004 and accumulated rainfall in the last month previous to the date of 2007 image. Thus, in dry years productivity is closely related to water available from recent past as opposed to over the year for wet years. Good fits (r^2 values higher than 0.88) were obtained between monthly decrease in water table depth and NDVI variables just in the dry year. These results demonstrate the important feedback between woody vegetation response to changes in the freshwater lens using empirical data and could apply to other systems with strong directional gradients in resources.

1. Introduction

Coastal system ecological processes are closely coupled to both atmospheric and oceanic drivers, all of which may be influenced by climate change. These ecosystems may be the most sensitive indicators of changing climate (Feagin et al., 2010). Sandy soils typical of North American Atlantic coast barrier islands have minimal water holding capacity which affect distribution and primary production of terrestrial communities. These communities are dependent on access to the soil freshwater lens, which varies temporally and spatially across the landscape. As summer evapotranspiration increases, freshwater capacity in the soil is reduced and may lead to associated drought stress and limited growth. In addition to evapotranspiration, rainfall, and limited groundwater recharge during the summer months, spatial variations in water availability are subject to plant water use. These effects are exacerbated by microtopography, with dune crests most susceptible to water stress than the lower elevation swales. Frequency and intensity of summer droughts are expected to increase in response to predicted shifts in global climate patterns (Karl et al., 2009). Shrub thickets represent the dominant woody community of many Atlantic coast barrier islands (Young et al., 2007). The primary species is *Myrica cerifera*, an evergreen, actinorhizal nitrogen fixing shrub. Interestingly, *Myrica* is characterized by rapid growth but also responds quickly to both salinity and drought stress (Naumann et al., 2007; Young et al., 1994; Zinnert et al., in press). Distribution is limited to low elevation swales with access to the freshwater lens. *Myrica* thickets are a strong indicator of summer drought relative to other terrestrial plant communities as these communities are most

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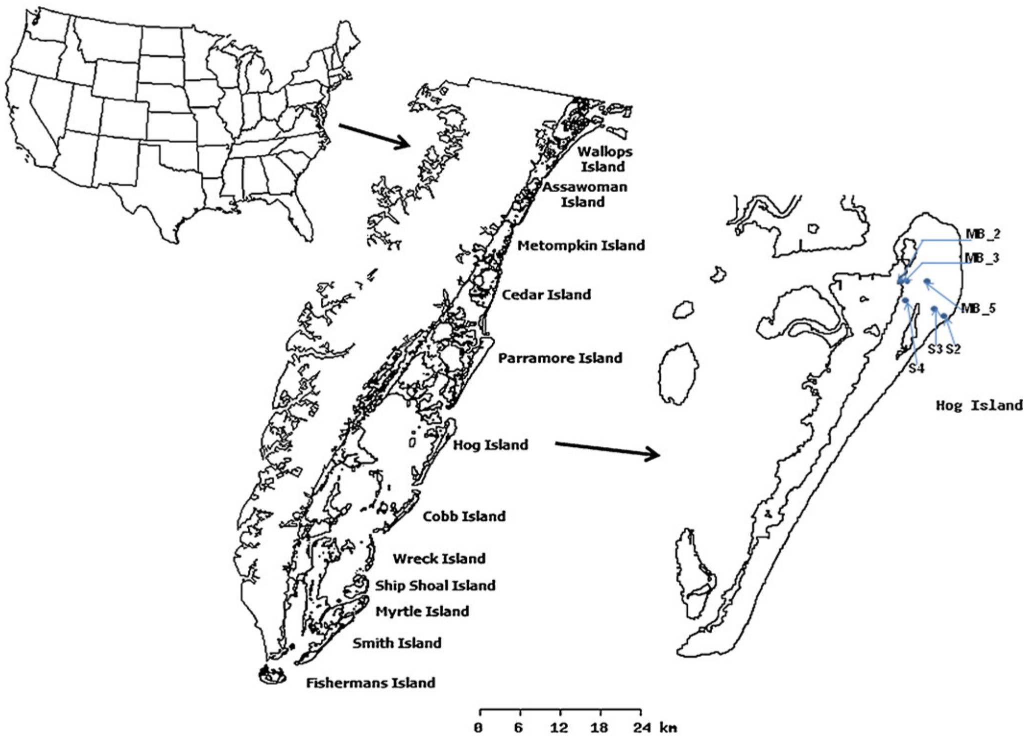

Fig. 1. Study site and location of wells (MB_2, MB_3, MB_5, S4, S3 and S2).

sensitive to changes in the freshwater lens. Methods for indicating areas most vulnerable to extended droughts have not been explored in coastal ecosystems.

Ability to assess how environmental changes affect dynamics of vegetation is increasingly important for better predictions of climate change effects. Popularity of the application of the Normalized Difference Vegetation Index (NDVI) in ecological studies has enabled quantification and mapping of green vegetation with the goal of estimating aboveground net primary productivity (ANPP) and other landscape-level fluxes (Pettorelli et al., 2005; Wang et al., 2003). NDVI is based on differences in reflectance in the red region (due to pigment absorption) and maximum reflectance in the near-infrared (caused by cellular structure); it is the most widely used index in remote sensing. It is closely related to a range of intercorrelated biomass variables such as leaf area index (LAI), leaf cover, chlorophyll per unit ground area, green biomass or green vegetation factor (Filella et al., 2004; Gamon et al., 1995). NDVI saturates easily and is not considered a good estimator of high LAI (Asner et al., 2000; Brantley et al., 2011); however, NDVI still retains ecological relevance as an indicator of green biomass change (Wang et al., 2003). NDVI can be a useful tool to couple climate and vegetation distribution and performance at large spatial and temporal scales (Pettorelli et al., 2005). Because vegetation vigor and productivity are related to hydrological variables (rainfall, evapotranspiration, etc.), NDVI serves as a surrogate measure of these factors at the landscape scale (Groeneveld and Baugh, 2007; Wang et al., 2003).

The linear response of vegetation NDVI to rainfall for regions with low vegetation cover and rainfall is well documented (Groeneveld and Baugh, 2007; Ji and Peters, 2003; Kawabata et al., 2001; Malo and Nicholson, 1990; Wang et al., 2003; Yang et al., 1998). Other studies have also analyzed trends of NDVI with other variables such as temperature (Wang et al., 2003), and evapotranspiration (Groeneveld, 2008). However, as relationships between NDVI and climatic factors are location-dependent, more detailed analyses are needed (Wang et al., 2003). Further, the sandy soils on barrier islands have a limited water holding capacity, thus the response of vegetation NDVI should be related to the groundwater table depth in the growing season.

Our goal was to determine the relevance of NDVI as an indicator of water availability to coastal woody vegetation. Specifically, we quantified responses to seasonal changes in precipitation and water availability through the groundwater lens by linking landscape level varitations in relative greeness of woody vegetation to past precipitation and hydrology. Throughout the summer growing season changes in woody productivity were assessed by using NDVI calculated from remote sensing imagery. We compared year to year variations in these patterns relative to variations in precipitation and water table depth at the appropiate temporal scale.

2. Materials and methods

2.1. Study site

The study is focused on Hog Island (37°40′N; 75°40′W), a barrier island located on the Eastern shore of VA, USA (Fig. 1). The northern end of the island is broad, with a series of dune lines separated by swales and ponds forming a chronosequence (Hayden et al., 1991). The primary woody vegetation is dense thickets of *M. cerifera*. Upland grasslands are dominated by *Spartina patens* and *Ammophila breviligulata*. Extensive marshes on the lagoon side of the island are dominated by *Spartina alterniflora*. Site records indicate a mean annual temperature around 15 °C and considerable inter annual variability of precipitation between 850 and 1400 mm per year. This variability renders summer drought a high probability of occurrence (Van Cleve and Martin, 1991).

The study period (2004–2008) was determined by the availability of spectral data in the summertime for both wet and dry years.