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Accuracy of optical image analysis compared to conventional vegetation measurements for estimating morphological features of emergent vegetation

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ABSTRACT

In this paper we evaluate the effectiveness of using optical image analysis to determine plant morphology for an emergent species of salt marsh vegetation, threesquare bulrush (*Schoenoplectus pungens*), and compare the results to conventional vegetation measurement methods. We find that mean stem height may be estimated optically to within 10% of mean stem height measured with conventional methods and that total above ground biomass may be estimated by lateral percent cover values between 0 and 70% ($R^2 = 0.89$, linear regression) within a 10 cm–60 cm depth of vegetation. Additionally, we show that stem height may be used to estimate stem diameter by linear regression ($R^2 = 0.94$). The product of the plant stem height, stem diameter and density measured by conventional methods are shown to correspond with the horizontal two-dimensional projection of vegetation estimated by image analysis. The optical method provided robust estimates when the depth of field is between 10 cm and 60 cm. When the depth of field exceeded 60 cm, the images were saturated, resulting in a loss of information.

1. Introduction

Vegetation in estuaries provides habitat for aquatic fauna and migratory waterfowl, shoreline stabilization, wave attenuation and marsh stability (Mitsch and Gosselink, 2007; Shepard et al., 2011). These and other ecosystem services are threatened by increases in sea level predicted from increased global temperature, thermal expansion and melting ice caps (Church and White, 2006; Vermeer and Rahmstorf, 2009; Jacob et al., 2012). One effect of rises in local sea level is the possibility of drowning marshes through increased inundation periods. In instances where migration of zones is not possible there may be either a partial or complete loss of a zone of vegetation (Kairis and Rybczyk, 2010; Stralberg et al., 2011; Carr et al., 2012). However, feedbacks between waves, vegetation, and sediment may provide increased resilience to rises in sea level if adequate sediment is available (Kirwan and Murray, 2007; Kirwan et al., 2010; Fagherazzi et al., 2012). Wave attenuation by vegetation has been demonstrated to occur as a result of plant biomass increasing the amount of dissipation experienced by a propagating wave (Dalrymple et al., 1984; Kobayashi et al., 1993; Asano, 2006; Augustin et al., 2009; Mullarney and Henderson, 2010). The resulting decrease in wave energy results in changes to local sediment deposition with increased accretion rates and decreased erosion, but may be density specific (Koch, 1999; D'Alpaos et al., 2007; Bouma et al., 2009; Mudd et al., 2010). Under certain conditions the positive feedback between vegetation density and sediment accretion may result in a vertically accreting marsh platform that acts as an important mechanism for marsh resilience to changes in mean sea level (Kirwan and Murray, 2007). Organic sediment deposition, flooding period, seasonal riverine discharge, and distance from tidal channels have also been shown to modify the surface elevation of a marsh (Cahoon and Reed, 1995; Cahoon et al., 1996). Given the predicted increase in global sea level rise as well as local variations in relative sea level rise, the effectiveness of vegetation to affect the vertical elevation of the marsh has

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important implications for maintaining a vegetated marsh platform and a diversity of vegetated and unvegetated zones.

Flume studies have shown that differences in vegetation structure, density, and flexibility affect the measured amount of wave attenuation (Bouma et al., 2010; Paul et al., 2012; Blackmar et al., 2014). While modeled wave attenuation is most simply described by stem density, height, and diameter (Dalrymple et al., 1984; Kobayashi et al., 1993), more robust models include stem flexibility (Asano, 2006; Mullarney and Henderson, 2010) and variations in the structure of the vegetation (Dubi and Torum, 2011). Recent studies have begun to highlight regional and local differences in vegetation by describing species densities, elevations, flexibility, heights, and leaf areas because these differences have been shown to be important in estimating wave attenuation (Feagin, 2008; Albert et al., 2013).

Methods to sample or characterize vegetation vary with vegetation stand structure. In estuaries, a quadrat (ranging from 0.25 m^2 to 1 m^2) is typically used to count stem density or to sub-sample stems randomly to determine the stem height and diameter. If stem densities are high, stems are often collected and processed in the laboratory resulting in destructive sampling of the vegetation, which is undesirable in certain cases. Multiple samples (replicates) are necessary to ensure statistical accuracy of measurements across a single stand of vegetation, or throughout an entire estuary to account for variations in vegetation structure due to hydroperiod, substrate and salinity (Feagin, 2008; Coulombier et al., 2012). The time and expense required to collect and process enough data using these vegetation measurement methods (termed ‘conventional methods’ in this manuscript for simplicity) is likely to be prohibitive for a large field based experiment. This has led to exploration of alternative methods, such as optical image analysis.

Neumeier (2005) applied an optical image analysis technique that allowed quantification of lateral obstruction and was shown to have a good correlation with above ground biomass for cordgrass species (*Spartina* spp.). This method extended the work of Möller and Spencer (2002) who estimated the average canopy height based on a horizontal image of vegetation, and Zehm et al. (2003) who photographed grassland vegetation. Möller (2006) related the photographic obscuration from salt marsh vegetation to wave attenuation. Straatsma (2008) extended the optical image technique to forest vegetation. Optical image analysis has recently been used as a component of sediment studies (Coulombier et al., 2012) and as a tool to compare LIDAR wave form data to vegetation structure. Despite the use of optical image analysis in all of these studies, destructive sampling of vegetation to collect morphologic data was conducted alongside the optical image analysis so that stem density and stem height could be measured as well. In each of these cases, stem height (or canopy height) is predicted from the optical image analysis and compared with the sampled data. Neumeier (2005) based the predicted canopy height to occur at either 1% or 10% lateral obstruction as estimated by linear interpolation, similar to Coulombier et al. (2012) who estimated the canopy height as occurring when lateral obstruction was $\leq$1%.

The work of Neumeier (2005) demonstrated the usefulness of optical imaging in calculating the lateral obstruction as a means to estimate flow hindrance but noted that it was not suitable for dense canopies and cautioned against problems of image saturation. In this paper we evaluate the potential for optical image analysis to be used as an accurate means to predict mean stem height, mean stem diameter (at base), stem density, and above ground biomass for the emergent estuarine species threesquare bulrush (*Schoenoplectus pungens*). Additionally, we explore the range of depths of vegetation for which optical image analysis provides robust results and identify the range of cover and biomass values for which linear regression may be applied. This species is simpler in structure than *Spartina* spp. and may be represented simply as a thin cylinder, making it a suitable species for estimating stem height and stem diameter from images of lateral obstruction. *Schoenoplectus pungens* is a common species along the Pacific Coast and typically occurs at the leading edge of vegetation at the margin of open water and marsh, where it is subject to wind generated waves during high tide (Albert et al., 2013). *Schoenoplectus pungens* is morphologically simple, being typified by a single straight stem, circular in cross section at the base and tapering to a triangular cross-section for most of the stem height, with few to no leaves. The location of *S. pungens* at the margin of open water and marsh within the estuary suggests it as a colonizing species that may prominently influence local sediment dynamics and aid in marsh evolution and stability. This paper describes the field site, the optical image analysis procedure and the conventional vegetation measurement methods and procedures for obtaining and statistically analyzing stem height, stem diameter, lateral obstruction and percent cover.

2. Methods

In August 2013, near the end of the growing season, digital photographs of vegetation were taken on a sand spit from the western edge of the estuary at Tillamook Bay, OR (lat 45.510324°, lon −123.943191°). This site is backed by a dike road to the west and the body of the estuary to the east. The site was chosen based on the uniformity of vegetation, easy access, and proximity to concurrent research areas. Vegetation was first photographed for optical image analysis at 10 cm intervals through a 1 m distance of *Schoenoplectus pungens*. These photographs were later used for image analysis as explained in detail in the next section. After all photographs were taken, vegetation was cut at the stem base, separated by 10 cm intervals, and bagged for processing in the laboratory.

2.1. Optical image analysis

Following the methodology of Zehm et al. (2003) and Neumeier (2005) a visually uniform section of vegetation was chosen for photographing. A mirror was placed at a 45° angle from the bed surface and supported with a wooden frame (Fig. 1a). A red backing board was positioned upright at 10 cm intervals from the base of the mirror. In this setup photographs were taken from above the mirror looking downwards such that each photograph encompassed the entirety of the vegetation for a given depth of vegetation (d). Each photograph was a cumulative representation of the vegetation so that the first photograph included vegetation between 0 cm and 10 cm, and the next photograph taken at 20 cm of vegetation included the vegetation between 0 cm and 20 cm, and so on up to a depth of 1 m. Photographs were taken at 10 cm intervals to capture the rate of saturation of the optical image analysis. This method allowed quantification of the range of depths of vegetation to photograph in order to estimate lateral obstruction and morphologic features of *Schoenoplectus pungens*. Photographs were taken using a Panasonic Lumix DMC LX5 camera in.raw file format. All photographs were spatially rotated, aligned, transformed, and cropped in Matlab version R2011a (Matlab) to ensure uniform orientation and pixel representation. Images were then converted from a full color RGB spectrum to a hue saturation that separated the green vegetation from the red backboard. Through a thresholding procedure, the images were converted to a binary black and white image (Fig. 1b). The thresholding procedure was performed in Matlab with code written for this experiment. The binary image was then divided into 10 cm vertical intervals, beginning from the ground (0 cm–10 cm, 10 cm–20 cm, etc.), and percent cover of black pixels (vegetation) were calculated to