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A method for using shoreline morphology to predict suspended sediment concentration in tidal creeks

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ABSTRACT

Improving mechanistic prediction of shoreline response to sea level rise is currently limited by 1) morphologic complexity of tidal creek shorelines that confounds application of mechanistic models, and 2) availability of suspended sediment measurements to parameterize mechanistic models. To address these challenges we developed a metric to distinguish two morphodynamic classes of tidal creek and tested whether this metric could be used to predict suspended sediment concentration. We studied three small tidal creeks in North Carolina, U.S.A. We collected suspended sediment at one non-tidal and two tidal sites in each creek and measured the wetland and channel width using a geographic information system. In each creek, tidal harmonics were measured for one year, sediment accretion on the salt marsh was measured for three years, and shoreline erosion was measured from aerial photographs spanning 50 years. Additional total suspended solids measurements from seven creeks reported in a national database supplemented our analysis. Among the three intensively studied creeks, shoreline erosion was highest in the most embayed creek (having a wider channel than the width of adjoining wetlands) and lowest in the wetland-dominated creek (having a channel narrower than the width of adjoining wetlands). Wetland sediment accretion rate in the wetland-dominated creek was four times higher than the accretion in the embayed creek. The wetland-dominated tidal creek had over twice the suspended sediment as the most embayed creek. Based on these results, we conclude that our metric of embayed and contrasting wetland-dominated creek morphology provides a guide for choosing between two types of morphodynamic models that are widely used to predict wetland shoreline change. This metric also allowed us to parse the 10 tidal creeks studied into two groups with different suspended sediment concentrations. This relationship between suspended sediment concentration and creek morphology provides a method to estimate sediment concentration for individual tidal creek shorelines from spatial data alone, enabling more accurate parameterization of shoreline change models.

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1. Introduction

Suspended sediment is a major determinant of the fate of salt marshes and a key parameter in numerical models of shoreline change and salt marsh response to sea level rise. Numerical models predict that lateral shoreline and vertical wetland changes are very sensitive to suspended sediment concentration: small differences in sediment supply can lead to tipping points between salt marsh inundation, accretion, retreat, and progradation (Kirwan et al., 2010; Fagherazzi et al., 2012; Mariotti and Carr, 2014). Despite this sensitivity, suspended sediment data are not often available across the spatial extent of an estuary. This forces researchers to estimate suspended sediment along broad areas of coastline using measurements at single locations (e.g., Schile et al., 2014) or continuous proxies such as distance from a sediment source (e.g., Rogers et al., 2012; Thorne et al., 2014). While net sediment flux may be the best indicator of wetland shoreline stability (Ganju et al., 2013; Ganju et al., 2015), suspended sediment concentration is easier to quantify and may help improve the predictive power of shoreline change models.

1.1. Predicting suspended sediment concentration

One approach for improving parameterization of suspended sediment concentration is to empirically relate suspended sediment with estuarine morphology. Because morphology can be measured from widely-available spatial data, unique predictions of suspended sediment concentration could be made for individual estuaries varying in size, shoreline position, and watershed attributes. One widely studied morphometric parameter is channel width convergence as reviewed

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by Savenije (2005) and Hughes (2012): the degree of funnel or trumpet-shape in estuary planform caused by tide, river discharge, and storm-driven wave action (Townend, 2012). When convergence is mapped over the topography of intertidal habitats, a dichotomy can be drawn between the wetland-dominated versus embayed portions of an estuary (Fig. 1; also see Ensign et al., 2014 for prior application of the terminology). The wetland-dominated portion of an estuary is a narrow alluvial channel embedded within an expansive wetland, while the embayed portion has a wide channel surrounded by a narrow, fringing intertidal wetland. Given the potential differences in current velocity between narrow and wide channels, this study examined the hypothesis that wetland-dominated creeks have higher suspended sediment concentration and subsequently higher wetland sediment deposition than wide, embayed estuaries (given equivalent watershed discharge, sediment load, and geologic setting).

1.2. Wetland shoreline classification for regional shoreline modeling

This empirical method for predicting suspended sediment concentration from estuarine morphology would improve the performance of morphodynamic models, yet applying those models at the regional scale necessary for environmental management and planning is another challenge. Models of shoreline change that can be applied regionally, such as the Sea Level Affecting Marshes Model (SLAMM) and NOAA's Sea Level Rise Viewer, lack consideration of fine-scale morphodynamic processes. While sophisticated morphodynamic models have been developed for well-studied systems (e.g., Carniello et al., 2014), the large data input requirements prohibit wide-spread applications over regional scales. In summary, advancement of the shoreline change models for management and planning requires inclusion of morphodynamic processes, but the morphologic complexity of large areas of coastline hinders the seamless implementation of sophisticated models at regional scales.

A potential solution is to use estuary morphology as a guide to where different groups of numerical models of wetland morphodynamics should be applied. Fig. 1 draws a dichotomy between two types of wetland shoreline morphologies and the models that describe them: those dominated by wave erosion (e.g., Phillips, 1986; Mariotti et al., 2010; Cowart et al., 2011; Marani et al., 2011; Mariotti and Fagherazzi, 2013; Mariotti and Carr, 2014; Currin et al., 2014) and those dominated by tidal currents (e.g., Wright et al., 1973; French and Stoddart, 1992; Friedrichs, 1995; Leonard, 1997; Christiansen et al., 2000; Fagherazzi and Furbish, 2001; Fagherazzi et al., 2004; Kirwan and Murray, 2007; Chen et al., 2011; Ensign et al., 2014). Ganju et al. (2013) describe how these differing morphodynamics create contrasting shoreline conditions (stable versus eroding) in adjoining estuarine creeks. Wide channels near an estuary's mouth are prone to wind-driven wave erosion, and these marsh boundaries are often accompanied by a shallow intertidal mudflat. Farther up the estuary, channel morphodynamics are the primary control on sediment delivery to adjoining marshes. Based on larger wind fetch and potentially lower suspended sediment, we expect that wetland shorelines erode faster in more embayed creeks. The wetland-dominated versus embayed characteristic introduced earlier may provide a criteria for differentiating zones of an estuary suitable for either group of the numerical models summarized in Fig. 1.

This study examined 1) how to predict suspended sediment concentration based on estuary morphology, and 2) how to differentiate shorelines with marsh-mudflat versus channel-marsh morphodynamic regimes based on estuary morphology. Suspended sediment concentrations, wetland deposition rates, and wetland shoreline change were measured to support the analyses. The rational was to help researchers parameterize mechanistic wetland shoreline change models and develop a tool to integrate these localized models with regional models. We performed analysis at the scale of small tidal creeks (sub-estuaries) where the spatial resolution of morphodynamic shoreline change models is often focused.

2. Methods

This study utilized data collected as part of a multi-disciplinary, 10-year environmental project at Marine Corp Base Camp Lejeune near Jacksonville, NC, USA. Three creek-marsh systems were selected for intensive study due to their similar watershed size, geology, and land use. Freeman Creek drains a 588-ha watershed above the tidal creek and is comprised of 26% forest and 4% developed land (Fig. 2). Traps Creek drains a 51-ha watershed above its tidal creek and is comprised of 10% forest and 12% developed land. French Creek drains a 807-ha watershed above its tidal creek and is comprised of 34% forest and 3% developed land. Limited data from additional tidal creeks from across the central and southern portion of NC were incorporated into the study to broaden the spatial scale of the analysis.

2.1. Morphometric analysis

ArcMap software (Esri, Redlands, CA, USA) was used to analyze channel and wetland width from spatial data in order to calculate the creek width to wetland width ratio along the longitudinal axis of each

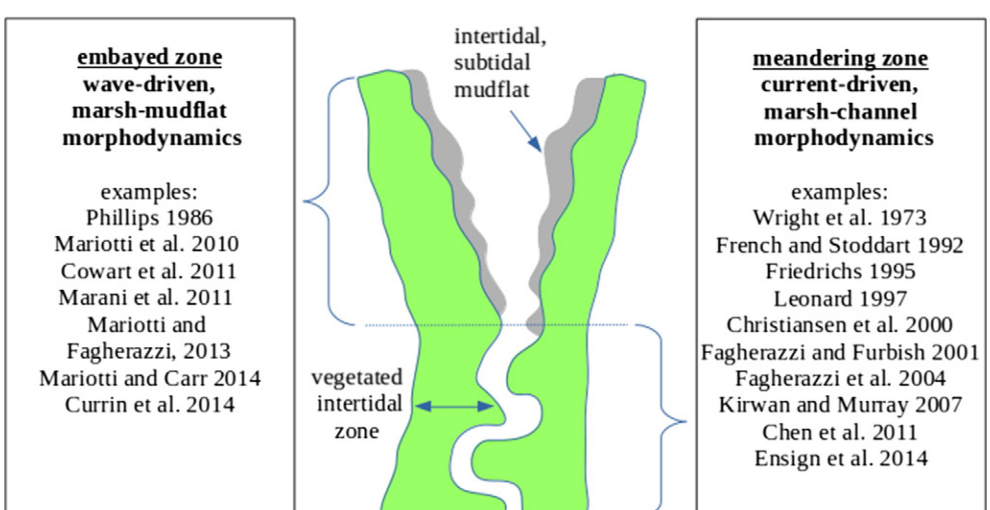

Fig. 1. Embayed versus wetland-dominated creek morphologies and examples of numerical models of each.

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