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The role of cross-shore tidal dynamics in controlling intertidal sediment exchange in mangroves in Cù Lao Dung, Vietnam

Karin R. Bryan[a,*], William Nardin[b], Julia C. Mullarney[a], Sergio Fagherazzi[c]

[a] Coastal Marine Group, School of Science, University of Waikato, Private Bag 3105, Hamilton, New Zealand
[b] Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, MD, USA
[c] Department of Earth and Environment, Boston University, USA

ABSTRACT

Mangroves are halophytic plants common in tropical and sub-tropical environments. Their roots and pneumatophores strongly affect intertidal hydrodynamics and related sediment transport. Here, we investigate the role tree and root structures may play in altering tidal currents and the effect of these currents on the development of intertidal landscapes in mangrove-dominated environments. We use a one-dimensional Delft3D model, forced using typical intertidal slopes and vegetation characteristics from two sites with contrasting slope on Cù Lao Dung within the Mekong Delta in Vietnam, to examine the vegetation controls on tidal currents and suspended sediment transport as the tides propagate into the forest. Model results show that vegetation characteristics at the seaward fringe determine the shape of the cross-shore bottom profile, with sparse vegetation leading to profiles that are close to linear, whereas with dense vegetation resulting in a convex intertidal topography. Examples showing different profile developments are provided from a variety of published studies, ranging from linear profiles in sandier sites, and distinctive convex profiles in muddier sites. As expected, profile differences in the model are caused by increased dissipation due to enhanced drag caused by vegetation; however, the reduction of flow shoreward in sparsely vegetated or non-vegetated cases was similar, indicating that shallowing of the profile and slope effects play a dominant role in dissipation. Here, tidal velocities are measured in the field using transects of Acoustic Doppler Current Profilers, and confirm that cross-shore tidal currents diminish quickly as they move over the fringe of the forest; they then stay fairly consistent within the outer few 100 m of the forest, indicating that the fringing environment is likely a region of deposition. An understanding of how vegetation controls the development of topography is critical to predicting the resilience of these sensitive intertidal areas to changes in inundation caused by sea-level rise.

1. Introduction

Coastal forests and wetland systems are particularly vulnerable to sea-level rise because of their characteristically low elevation (Blankespoor et al., 2014). Many coastal environments in tropical and semi-tropical areas are populated by mangrove forests (Krauss et al., 2013), which are tree species tolerant of salinity (Krauss et al., 2008). The risk of inundation is also compounded by the intense population pressure associated with large deltas, which are home to many of these mangrove shorelines. These deltas are reliant on a rich sediment supply for their existence (Brown and Nicholls, 2015). Deltaic surfaces respond to the complex interplay between sediment supply, compaction and sea-level oscillations. Some of the key questions facing managers are whether the rate of sediment supply is large enough to offset predicted rates of sea-level rise, when the subsidence effects are taken into account (Krauss et al., 2013; Syvitski et al., 2009).

Mangroves are under threat globally (Duke et al., 2007). Areas such as the Red River Delta and the Mekong Delta in Vietnam have lost much of their forested surface due to land-use conversions and shrimp farming (Seto and Fragkias, 2007; Thu and Populus, 2006). Removing the trapping capacity and high friction environment associated with mangroves could affect our ability to capture coastal sediments and maintain these low-lying vulnerable areas during sea-level rise. Moreover, such environments are hypothesized to be critical in protecting the coast from storms and tsunamis (Kathiresan and Bingham, 2005).

Understanding the factors that drive morphological evolution in mangrove-dominated environments is therefore critical to predicting the stability of these regions. There are a large number of processes that influence morphological change in such regions (such as tidal currents, waves, turbulence production, sediment supply, sediment texture, compac-

* Corresponding author.
E-mail address: karin.bryan@waikato.ac.nz (K.R. Bryan).

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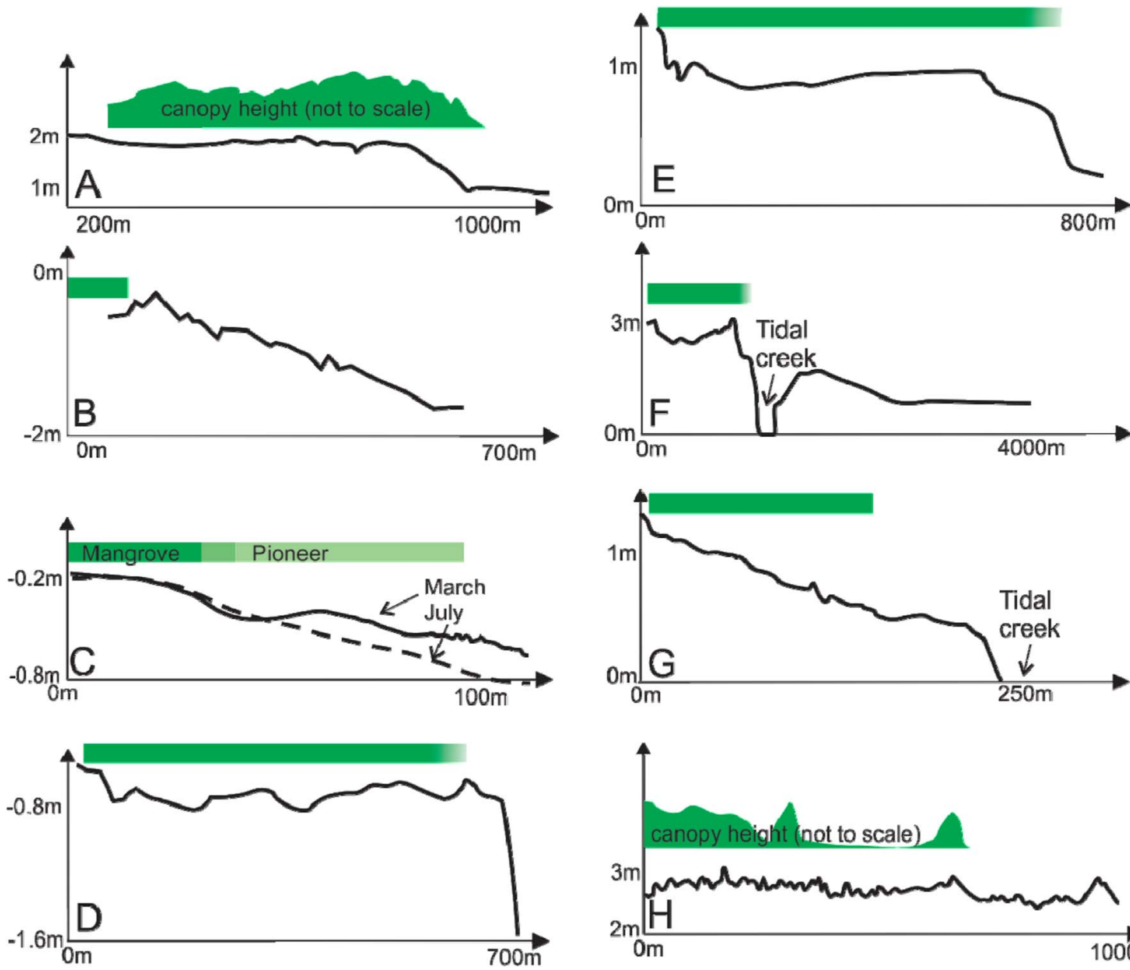

Fig. 1. A Upper intertidal profile from the *Avicennia*-dominated muddy mangrove forest, Firth of Thames, New Zealand (Lovelock et al., 2010). B: *Kandelia candel*-dominated sandy mangrove forest, Do Son, Red River Delta, Vietnam (Quartel et al., 2007). C: Mixed species mangrove forest, Ba Lat Estuary, Red River Delta, Vietnam (Van Santen et al., 2007). D: Mangrove forest profile from a mixed mangrove forest, Hang Hai, Can Gio Mangrove Biosphere Reserve, Southern Vietnam, Vietnam (Vo-Luong and Massel, 2008). E: Profile from an *Avicennia*-dominated mangrove forest, Queensland, Australia (Knight et al., 2009) (the dip in elevation offshore is also where a tidal creek occurs). F. Mud-dominated intertidal profile along French Guiana (near the Amazon) (*Avicennia*-dominated) (Anthony et al., 2008, 2010). G: Unpublished profile from a sand *Avicennia*-dominated Whangapoua Estuary, New Zealand, collected by the authors using RTK-GPS. H. *Avicennia*-dominated muddy profile from French Guiana (Proisy et al., 2009). In all panels, the mangrove canopy is represented by a filled green line, or a green rectangle for cases where the canopy densities and heights were not provided. Datums are local and vary between studies. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tion and consolidation), all of which can interact to cause both positive and negative feedbacks. Here we focus on the role of cross-shore tidal currents and how they might play a role in shaping intertidal morphology in mangroves. To allow controlled exploration of the feedbacks in a tropical mangrove system, we use idealised 1D numerical modelling, with realistic bed profiles and vegetation characteristics, to study how vegetation density and contrasting morphology change the cross-shore tidal flow. Past work suggests that the effect of vegetation and shallowing water is to increase the frictional effect on tidal currents, which can either dissipate the tidal wave energy, or cause the tidal wave to shoal (e.g. Parker, 1984). The latter effect can increase tidal currents and change tidal asymmetry. We aim to determine which of these effects is more dominant over mangroves shorelines. We then use the model to infer the changes to sediment supply and morphological evolution that might eventuate under these tidal characteristics. The model results are compared qualitatively to measurements collected at Cù Lao Dung on the Mekong River delta, Vietnam.

2. Background

Sediment supply to intertidal coastal environments is driven by the balance of sediment fluxes between the incoming (flooding) and the outgoing (ebbing) tide (Fagherazzi et al., 2013; Friedrichs, 2011; Ganju et al., 2017). In turn, sediment flux is controlled by the strength of the currents, the bed shear stress, and the concentration of suspended sediment in the water column. Suspended sediment can depend both on the local bed shear stress (as in the case of coarser material), but also on the bed shear stress upstream of the sampling site, such as situations in which settling velocities are low, and sediment can be transported long distances before ultimately depositing on the sea bed. The intertidal morphology can contribute to current asymmetry with deep intertidal areas tending to cause flood currents to dominate over ebb currents, whereas channelized morphologies with shallow intertidal areas tend to cause ebb dominance (Friedrichs and Aubrey, 1988). Wetting and drying can influence the local tidal asymmetry, so that areas that are only inundated on high tide are often flood-dominated regardless of the conditions in the lower channels (Hunt et al., 2015, 2016). This spatial pattern in flood/ebb asymmetry favors accretion on the tidal flats and channel erosion, ultimately resulting in the development of a channelized drainage network (van Maanen et al., 2013). Superimposed on the tidal current asymmetry, are gradients in bed shear stress and sediment concentration. If the drop in current associated with slack water is sufficiently prolonged, fine sediments settle from the water column and are not transported seaward on the following ebb tide. Such effects (called settling lag effects or Lagrangian effects) cause accretion high on the tidal flat, and a characteristically convex shape to develop (Friedrichs, 2011).