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Influence of vegetation on spatial patterns of sediment deposition in deltaic islands during flood

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ABSTRACT

River deltas are shaped by the interaction between flow and sediment transport. This morphodynamic interaction is potentially affected by freshwater marsh vegetation (e.g. *Sagittaria* spp.and *Typha* spp. in the Mississippi delta, USA) on the exposed surfaces of emergent deltaic islands. The vulnerability of deltaic islands is a result of external forces like large storms, sea level rise, and trapping of sediment in upstream reservoirs. These factors can strongly determine the evolution of the deltaic system by influencing the coupling between vegetation dynamics and morphology. In the last few years, models have been developed to describe the dynamics of salt marsh geomorphology coupled with vegetation growth while the effect of freshwater vegetation on deltaic islands and marshes remains unexplored. Here we use a numerical flow and sediment transport model to determine how vegetation affects the spatial distribution of sediment transport and deposition on deltaic surfaces during flood. Our modeling results show that, for an intermediate value of relative vegetation height and density, sedimentation rate increases at the head of the delta. On the other hand, large values of relative vegetation height and density promote more sedimentation at the delta shoreline. A logical extension of our results is that over time intermediate values of relative vegetation height and density will create a steeper-sloped delta due to sediment trapping at the delta head, whereas relatively taller vegetation will create a larger, but flatter delta due to sediment deposition at the shoreline. This suggests intermediate relative vegetation height and density may create more resilient deltas with higher average elevations.

1. Introduction

Deltaic islands are individual marsh and sediment platforms surrounded on all sides by distributary channels or open water. In many river deltas, these islands are the fundamental building blocks that create deltaic land (Fig. 1). Previous work ([21] and references therein) has focused on their initial subaqueous formation due to sedimentation associated with turbulent jet expansion at the river mouth, whereas few studies have considered sedimentation processes on these islands once they are emergent and colonized with vegetation. This is surprising because sedimentation dynamics on vegetated island tops determines vertical accretion rates and delta resiliency to rising relative sea level. Understanding sedimentation dynamics on deltaic islands is critical since rising relative sea-levels are threatening to drown most of the world's deltas [55,57]. The purpose of this study is to investigate how the processes of mineral sedimentation on emergent deltaic islands are influenced by vegetation. This is especially relevant given the feedbacks between vegetation, mineral sediment transport, and morphodynamics shown to exist in fluvial systems [42,56] and salt marshes [12,20,29,40,58,59].

Predicting deltaic island formation is complex because of the interactions of waves, tides, buoyancy effects, and longshore currents [21,64]. We know from detailed numerical experiments how turbulent jet dynamics create sedimentation patterns leading to river mouth bar and eventually deltaic island formation [8,15,22,50], how those patterns are influenced by waves and tides [34,43,44], and how those patterns change as a function of sediment characteristics and properties [7,16,23].

Noticeably missing from these studies is an exploration on how vegetation influences sedimentation on deltaic islands. Vegetation probably has little effect on the initial formation of subaqueous deposits at the river mouth because water is too deep for plant growth (see review in [21]). Once the island emerges and becomes nearly subaerial, it is typically shaped like a chevron pointing upstream, with sandy levees on the margins and a relatively smooth lower-lying interior (Fig. 1). The relief between the levee and island interior is usually small, but can vary depending on island age. In Wax Lake delta, Louisiana, USA, it is around 50 cm

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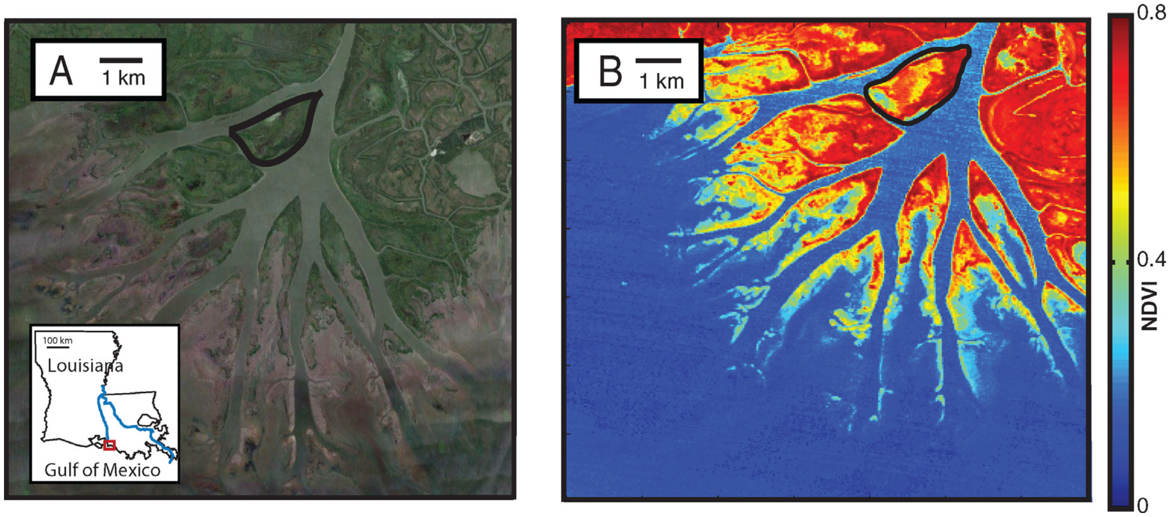

Fig. 1. (A) 2013 aerial photo of Wax Lake Delta, LA, USA (courtesy of Terra Metrics, Google Earth). Black solid line shows an example of island in Wax Lake Delta. (B) Example image of normalized difference vegetation index (NDVI) data for Wax lake delta, LA, USA. Image is Landsat 7 ETM+ from Dec. 20th 2012.

Notation

C_b	alluvial bed roughness according with to Chezy, $m^{1/2}$ s^{-1};
C_b'	effective bed roughness under vegetation according with to Chezy, $m^{1/2}$ s^{-1};
C_D	drag coefficient, -;
C_{rs}	representative Chezy value for vegetation totally submerged, $m^{1/2}$ s^{-1};
C_r	representative Chezy value for vegetation partially submerged, $m^{1/2}$ s^{-1};
c_{eq}	equilibrium sediment concentration, kg m^{-3};
D	stems diameter, m;
D_{50}	sediment median grain size, μm;
$\overline{D_v}$	averaged water depth with vegetation, m;
$\overline{D_{nv}}$	averaged water depth without vegetation, m;
$\overline{U_v}$	averaged water velocity with vegetation, ms^{-1};
$\overline{U_{nv}}$	averaged water velocity without vegetation, ms^{-1};
f_s	reduction factor for vegetation totally submerged,-;
f_{ns}	reduction factor for vegetation partially submerged,-;
Q_i	river discharge, m^3s^{-1};
Qs_i	in-coming sediment flux, kg s^{-1};
Qso	out-coming sediment flux, kg s^{-1};
q	water flux, m^3s^{-1};
m	number of stems for square meter, m^{-2};
n	vegetation density, m^{-1};
c	suspended sediment mass concentration, kg m^{-3};
g	gravitational acceleration, m s^{-2};
h	water depth, m;
h_v	vegetation height, m;
$\hat{h}_v$	non dimensional vegetation height, m;
i	slope, -;
k	van Karman constant, -;
R_W	water flux ratio, -;
R_U	water velocity ratio, -;
R_D	water depth ratio, -;
F_B	water flux computed by *Delft3D* on deltaic islands, m^3s^{-1};
F_{Bnoveg}	water flux computed by *Delft3D* on non-vegetated deltaic islands, m^3s^{-1};
F_W	normalized water flux computed by *Delft3D* on deltaic islands, -;
η	elevation of the water surface, m;
t	time, s;
$\bar{u}$	depth averaged flow velocity, m s^{-1};
u_u	flow velocity above vegetation, m s^{-1};
u_v	flow velocity inside vegetation, m s^{-1};
U	time averaged x-direct fluid velocity, m s^{-1};
V	time averaged y-direct fluid velocity, m s^{-1};
x,y	planform directions, m;
Δsed	sediment trapped in Delta slice, kg;
ρ	fluid density, kg m^{-3};
τ_b	bed shear stress, N m^{-2};
T_S	adaptation time, s;
$\hat{\tau}_{ch}$	mean channels shear stress, N m^{-2};
$\hat{\tau}_{bar}$	mean island shear stress, N m^{-2};
$\lvert\hat{\tau}_{ch}\rvert_v$	mean channels shear stress with vegetation, N m^{-2};
$\lvert\hat{\tau}_{ch}\rvert_{nv}$	mean channels shear stress without vegetation, N m^{-2};
$\lvert\hat{\tau}_{bar}\rvert_v$	mean channels shear stress with vegetation, N m^{-2};
$\lvert\hat{\tau}_{bar}\rvert_{nv}$	mean channels shear stress without vegetation, N m^{-2};
τ_{bv}	bed shear stress in presence of vegetation totally submerged, N m^{-2};
$\tau_{bv,ns}$	bed shear stress in presence of vegetation partially submerged, N m^{-2};
τ_v	shear stress due to the vegetation drag, N m^{-2};
τ_t	total shear stress, N m^{-2};
ν_H	horizontal eddy viscosity, m^2 s^{-1};
ν_V	vertical eddy viscosity, m^2 s^{-1};
$\varepsilon_{S,x}$, $\varepsilon_{S,y}$, $\varepsilon_{S,z}$	sediment eddy diffusivity along three coordinate axis directions, m^2 s^{-1};

[39,46,53]. Vegetation that colonizes these islands is affected by small elevation differences. These elevation differences can change the hydroperiod, which is a key variable in determining species