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Sedimentation within and among mangrove forests along a gradient of geomorphological settings

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ABSTRACT

Coastal wetlands provide important ecological services to the coastal zone, one of which is sediment retention. In this study we investigated sediment retention across a range of geomorphological settings and across vegetation zones comprising coastal wetlands. We selected six coastal wetlands dominated by mangroves over a gradient from riverine to tidal settings in Southeast Queensland, Australia. Each site was comprised of three distinct vegetation communities distributed as parallel zones to the coast line: seaward fringe mangroves, landward scrub mangroves and saltmarsh/ cyanobacteria mat of the high intertidal zone. We measured suspended sediment retention and sedimentation rates. Additionally, in order to assess the origin of sediment transported and deposited in the mangroves, glomalin, a novel terrestrial soil carbon tracer, was used. Our results show a mean average sedimentation of 0.64 ± 0.01 mg cm^{-2} spring tide^{-1}, which was variable within sites, regardless of geomorphological setting. However, geomorphological setting influenced spatial patterns of sediment deposition. Riverine mangroves had a more homogeneous distribution of sediments across the intertidal zone than tidal mangroves, where most sedimentation occurred in the fringe zone. Overall, the fringe zone retained the majority of sediment entering the coastal wetland during a tidal cycle with 0.90 ± 0.22 mg cm^{-2} spring tide^{-1}, accounting for 52.5 ± 12.5% of the total sedimentation. The presence of glomalin in suspended sediments, and thus the relative importance of terrigenous sediment, was strongly influenced by geomorphological setting, with riverine mangroves receiving more glomalin in suspended solids than tidal mangroves. Glomalin was also differentially deposited within the vegetation zones at different geomorphological settings: primarily at the fringe zone of tidal mangroves and within the scrub zone of riverine mangroves. The differences we observed in the spatial distribution of sedimentation and the difference in the origin of the sediment deposited in riverine and tidal mangroves are likely to have an impact on ecological processes.

1. Introduction

Coastal wetlands are comprised of various vegetation communities such as mangroves, saltmarsh and cyanobacteria mats. These vegetation communities are often distributed as parallel zones to the coast line, responding to an elevation gradient, which determines tidal flushing frequency (Robertson and Alongi, 1992). Fringe mangroves occupy the lowest elevations, where they are frequently flooded by neap and spring tides, while scrub mangroves occupy mid elevations, where they are flooded only during spring tides (e.g. Furukawa et al., 1997). Saltmarsh and cyanobacteria mat communities occupy the highest elevation zone, which is rarely flooded by tides. Although, mangroves, saltmarsh and cyanobacteria mat communities coexist in some regions, mangroves are the dominant vegetation community in tropical and subtropical coastal wetlands (Kangas and Lugo, 1990).

Mangroves are generally known for being depositional sites for sediment and associated carbon and nutrients (Eyre, 1993; Furukawa and Wolanski, 1996). Thereby, mangroves aid in the protection of adjacent seagrass and coral reef ecosystems from the negative impacts of nutrient enrichment and sedimentation (Ewel et al., 1998; Valiela and Cole, 2002). The role of mangroves in enhancing sedimentation, which often results in expansion of mangrove habitats, is well known. Above-ground root systems and stems enhance sediment deposition that further promotes mangrove growth and expansion (Furukawa and Wolanski, 1996). The accretion capacity of

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mangroves is the result of a complex root system that increases friction and reduces tidal current velocities (Wolanski et al., 1992). Mangrove roots also generate turbulence that results in fine sediment remaining in suspension when entering the forest with the flood tide (Shahbudin et al., 1999). As the tide progresses through the forest, the current slows. During slack high tide, as current velocities approach zero, flocs are deposited (Furukawa et al., 1997). While settling, the flocculated material increases in size by an order of magnitude and as a result, ebb tide currents are often too slow to resuspend them (Furukawa and Wolanski, 1996). These processes result in sedimentation and accretion that can be extremely rapid in some settings (e.g. vertical accretion of 4 cm yr^{-1}; Alongi et al., 2005).

Spatial patterns of sedimentation within coastal wetlands are variable. Some sites experience higher sedimentation rates at the fringe zone relative to areas farther landward (Furukawa and Wolanski, 1996). This sedimentation pattern generally follows the exponential decrease of suspended sediment concentration during tidal inundation, which decreases from the seaward fringe to the scrub zone (Furukawa and Wolanski, 1996). However, others sites have shown different spatial patterns. For example, at the Red River in Vietnam, most of the sediment that enters with the high tide is retained not in the fringe zone, but rather on the riverbank mudflats lying seaward of the mangroves (Van Santen et al., 2007).

Sedimentation patterns are likely to be influenced by the geomorphological setting in which a mangrove community grows. Geomorphological classifications are based on the principle that the physical forces acting on a shoreline will not only shape it, but will continuously influence processes occurring within that shoreline. Thom (1982) classified the mangroves according to their geomorphological setting as river dominated, tide-dominated, wave-dominated, composite river-wave-dominated or as drowned bedrock valley. Within Thom's five settings (Thom, 1982), the greatest contrast is between riverine mangroves, which are dominated by unidirectional flows, and tidal mangroves, characterized by bidirectional flows (Wolanski et al., 1992). In this scheme, riverine mangroves are characterized by high nutrient influx and strong outwelling (Woodroffe, 1992). In contrast, tidal mangroves have bidirectional fluxes of water and suspended material often with little net export and even with overall import of materials (Woodroffe, 1992). Based on this theoretical analysis, it is expected that tidal mangroves will have higher suspended sediment retention and sedimentation rates than riverine mangroves.

Geomorphological classifications are often used to explain ecological differences between mangrove forests (e.g. Twilley et al., 1998; Ryan et al., 2003). Geomorphological classifications of mangroves also underlie theoretical models estimating the magnitude of mangrove ecological services (Ewel et al., 1998) and the effects of climate change on the coastal zone (Nicholls et al., 1999; Ryan et al., 2003). However, the role of the geomorphological setting in determining ecological processes within mangroves, such as sediment retention, has not yet been quantitatively assessed.

Sediment deposited in mangroves originates from a range of sources. Allochthonous sediment arrives from external sources, either terrestrial or oceanic, while autochthonous sediment is resuspended. Determining the source of sediments deposited within mangroves is required to quantify the mangrove net retention capacity of terrestrial-derived materials as well as to understand the linkages between terrestrial and marine ecosystems. However, the ability to trace the origin of allochthonous or autochthonous sediment has proven challenging.

Techniques employed to trace the origin of deposited sediment include a range of chemical and physical markers. Although many of these techniques are extremely powerful, especially when used with a multiple tracer approach (Raymond and Bauer, 2001), replication is often limited (Hedges et al., 1986). Despite best efforts, some of the multiple tracer studies lead to difficulty in interpretation of results (Wheatcroft et al., 1996), variability of performance of markers within sites (Prahl et al., 1994) and overlapping of signals (Rodelli et al., 1984). Therefore, a reliable, universal, simple and inexpensive tracer of terrigenous origin is desirable.

Glomalin is a glycoprotein produced by symbiotic arbuscular mycorrhizal fungi (Wright and Upadhyaya, 1998). Arbuscular mycorrhizal fungi are associated with the roots of most terrestrial plants, but not with mangrove roots, except in conditions of low salinity (Sengupta and Chaudhuri, 2002). Glomalin is very resistant to decomposition, having a half-life of 7–42 years (Rillig et al., 2001). It accumulates in soils to form a significant proportion of soil carbon (approximately 5% of soil carbon) (Rillig et al., 2001; Lovelock et al., 2004). Variation in the glomalin concentration in soils depends on a range of environmental and plant factors. Soil glomalin concentration is significantly correlated with the organic carbon content in soils, fertility, cultivation regime and plant community productivity (Wright and Upadhyaya, 1996; Lovelock et al., 2004; Treseder and Turner, 2007). Despite this variation, the unusual characteristics of glomalin (high chemical stability and its known terrestrial origin) make it a promising candidate as a terrigenous tracer. Glomalin has been successfully used in the study of development of soils in accreting river systems (Harner et al., 2004). In this study, we use glomalin to investigate patterns in terrestrial soil carbon deposition in coastal wetlands.

To examine variation in sediment retention and sedimentation in mangroves over a range of geomorphological settings and to determine the patterns of glomalin deposition, we analysed a number of sites ranging from riverine to tidal in Southeast Queensland. We measured suspended sediment retention and sedimentation rates within different zones of the wetland and compared the amount of glomalin found in suspended and deposited sediments in each geomorphological setting and vegetation zone. In this study, we also used the proportion of reactive glomalin as an complementary information, helping us to discern between the "younger" deposited sediment recently derived from terrestrial origin, from the "older" deposited sediment of marine origin and/or resuspended material. Our expectation was that riverine mangroves would have lower sedimentation rates and sediment retention than tidal mangroves, and that geomorphological setting influence the spatial distribution of sedimentation within the mangroves. Furthermore, we expected riverine mangroves to have higher glomalin concentrations and more reactive glomalin in the suspended and deposited sediment than tidal mangroves, therefore, providing a signature of a recent and strong terrestrial influence.

2. Methodology

2.1. Study sites

The sites chosen for this study are located in the Southeast Queensland biogeographic region. The estuaries sampled are situated within Moreton Bay, with the exception of the Mooloolah River, which lies 40 km north of the Bay (Fig. 1). The tidal regime with the region is semidiurnal and the tidal range is low (<2 m, Australian Estuarine Database Survey, 1998). The region is classified as subtropical, experiencing moderate temperatures all year round. The mean annual maximum temperature of the area is 25.4 °C and the minimum is 15.7 °C (Australian Bureau of Meteorology: http://www.bom.gov.au/index.shtml. Brisbane Airport Station; 1951–2000). The climate is characterized by a dry winter with a total rainfall of 64 mm (June to August) and a hot summer with a total rainfall of 597 mm (December to February). During the summer, the