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The impact of pre-restoration land-use and disturbance on sediment structure, hydrology and the sediment geochemical environment in restored saltmarshes

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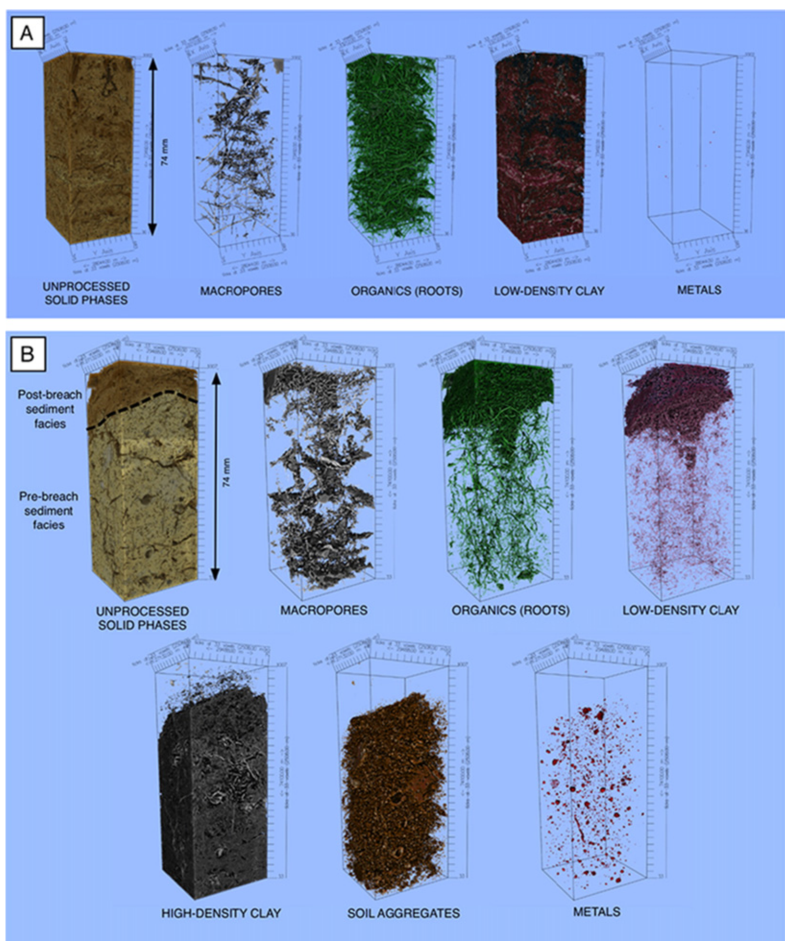
HIGHLIGHTS

- Poor plant species diversity in restored saltmarshes is attributed to poor drainage.
- Micro computed X-ray tomography provides novel data on sediment structure
- Previous land-use irreversibly modifies sediment structure and porosity networks.
- Restored saltmarshes have reduced flood storage capacity and solute mobility.
- It is important to consider hydrological regime in saltmarsh restoration

GRAPHICAL ABSTRACT



Sediment phases in A) natural and B) de-embanked saltmarsh cores.

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ABSTRACT

Saltmarshes are being lost or degraded as a result of human activity resulting in loss of critical ecosystem services including the provision of wild species diversity, water quality regulation and flood regulation. To compensate, saltmarshes are being restored or re-created, usually driven by legislative requirements for increased habitat diversity, flood regulation and sustainable coastal defense. Yet, there is increasing evidence that restoration may not deliver anticipated ecosystem services; this is frequently attributed to poor drainage and sediment anoxia. However, physical sediment characteristics, hydrology and the sediment geochemical environment are rarely examined in restoration schemes, despite such factors being critical for plant succession.

This study presents the novel integration of 3D-computed X-ray microtomography to quantify sediment structure and porosity, with water level and geochemical data to understand the impact of pre-restoration land use and disturbance on the structure and functioning of restored saltmarshes. The study combines a broad-scale investigation of physical sediment characteristics in nine de-embanked saltmarshes across SE England, with an intensive study at one site examining water levels, sediment structure and the sediment geochemical environment. De-embankment does not restore the hydrological regime, or the physical/chemical framework in the saltmarshes and evidence of disturbance includes a reduction in microporosity, pore connectivity and water storage capacity, a lack of connectivity between the sub-surface environment and overlying floodwaters, and impeded sub-surface water flow and drainage. This has significant consequences for the sediment geochemical environment. This disturbance is evident for at least two decades following restoration and is likely to be irreversible. It has important implications for plant establishment in particular, ecosystem services including flood regulation, nutrient cycling and wild species diversity and for future restoration design.

1. Introduction

Saltmarshes are globally important environments occupying c. 5.1 Mha of the Earth's surface (Pendleton et al., 2012) and providing a range of ecosystem services (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). However, saltmarshes are threatened by sea level rise, human population growth, urbanization and pollution, causing degradation or loss of habitat worldwide. This can result in the loss of critical ecosystem services including the provision of nursery habitats, coastal defense and detoxification (Barbier et al., 2011). To compensate, a large number of coastal restoration projects have been implemented in recent decades, frequently driven by legislative requirements for improved biodiversity e.g. the EU Habitats Directive and Birds Directive (European Parliament and the Council of the European Union, 1992), and for sustainable coastal defense and flood storage (Esteves, 2013). Increasing evidence suggests that restored saltmarshes, recreated through reversion to tidal inundation of previously drained and defended land, have lower biodiversity and ecosystem service delivery than anticipated (e.g. Mazik et al., 2010; Mossman et al., 2012; Esteves, 2013; Brooks et al., 2015) and that, whilst environmental enhancement has been achieved, there may be consequences for ecosystem functioning (Doherty et al., 2011). Therefore, in order to improve the delivery of ecosystem services, there is a critical need to understand both the structure and function of restored saltmarshes.

Restoration aims to recover saltmarsh ecosystem structure and function to reference conditions and assumes that as long as the physical and/or-chemical structure of the system is restored, colonization by saltmarsh plants should follow (Borja et al., 2010). Surface elevation of saltmarshes is considered the most important physical/structural parameter in restoration design (Howe et al., 2010), having a direct influence over plant colonization through controlling the hydroperiod and hence sediment aeration. The hydroperiod concept, defined as the proportion of time for which a wetland is submerged (Mitsch and Gosselink, 2007), is however over-simplistic with water depth, tidal regime, frequency of tidal flooding, distance to creek drainage networks and precipitation/evapotranspiration all influencing sub-surface saturation and net water flux (Ursino et al., 2004; Eaton and Yi, 2009; Spencer and Harvey, 2012; Xin et al., 2013a, 2013b). The flux of pore water through the sub-surface environment is also critical for controlling abiotic conditions in the sediment including redox status, nutrient availability, salinity and the presence of potentially toxic S^{-}, Mn^{2+} and Fe^{2+}, all of which may be as critical as the hydroperiod for determining plant growth and ecological zonation (Silvestri et al., 2005; Wolters et al., 2008; Smith et al., 2009; Erfanzadeh et al., 2010; Howe et al., 2010; Engels et al., 2011; Davy et al., 2011; Xin et al., 2013a, 2013b; Wilson et al., 2015). Flux and transport pathways of pore water through the sub-surface environment and surface-groundwater interactions are also controlled by the sediment texture (e.g. porosity) and structure (e.g. stratigraphy) (Xin et al., 2009; Wilson and Morris, 2012). Yet, whilst they may potentially be important physical system parameters that influence ecosystem structure and function in restored saltmarshes they are rarely studied.

Saltmarshes are frequently re-created from land that has previously been embanked to prevent coastal inundation and drained, usually for agricultural purposes. This results in a legacy of significant pre-restoration disturbance including de-watering, compaction and mineralization of organic matter. Such disturbance also impacts sediment structure, including the collapse of pore space (Hazelden and Boorman, 2001; Boorman et al., 2002; Ellis and Atherton, 2003) resulting in poor drainage (Crooks et al., 2002; Grismer et al., 2004; Montalto et al., 2007; Tempest et al., 2015) and this pre-restoration disturbance may trigger saltmarsh recovery towards an alternative state, as the speed and rate of ecosystem structure recovery may be dependent upon such abiotic factors (Moreno-Mateos et al., 2012). Therefore, even though it is recognized that poor drainage and sediment anoxia may be responsible for poor species composition in restored saltmarshes (Mossman et al., 2012) there is a general lack of understanding of the impact of restoration on sedimentary processes (Esteves, 2013). Furthermore, there has been little detailed investigation of sediment structure and how this may influence sub-surface hydrology and the sediment geochemical environment.

This study investigates the impact of pre-restoration land use and disturbance on sediment structure in saltmarshes restored through de-embankment, and explores the implications for sub-surface hydrology and the sediment geochemical environment as limiting factors for the successful restoration of saltmarshes. A novel combination of 3D structural sedimentology, geochemistry and hydrological datasets permits evaluation of the sediment structural controls over saltmarsh restoration at a number of locations in southeast England and considers whether structural characteristics, including the hydrological regime, of the saltmarsh have been restored.