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Long term salt marsh vertical accretion in a tidal bay with reduced sediment supply

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ABSTRACT

Because of damming and intensive human activities, the sediment supply to many estuaries and deltas are dramatically decreasing. In the Oosterschelde estuary (southwest Netherlands), a storm surge barrier (SSB) and two compartmentalization dams were built in the 1980s to protect the densely inhabited inland against flooding. After these constructions, the tidal range and mean high water level in the Oosterschelde decreased by about 12% and suspended sediment concentrations in the channels dropped by 52–70% compared to the pre-barrier conditions. The vertical accretion rates of the three largest salt marshes (Rattekaai, Sint Annaland and Slaak) in the Oosterschelde in response to this decreased sediment supply were investigated. There was a general accreting trend over the entire post-barrier period (1988–2011) in all three marshes. The predicted slowdown in accretion rates by De Jong et al. (1994) did not persist, although accretion rates were lower than in the pre-barrier period More than 20 year observations from kaoline horizon markers showed variation of accretion rates within and among marshes .Year-to-year variation in accretion rates was large, but only weakly (not significantly) related to the duration and frequency of marsh overflow and over-marsh extreme flooding events. However, storm events are hypothesized to be responsible for the observed trends, but our observation lack the temporal resolution to identify specific storm events. Salt marshes in the Oosterschelde are expected to survive under the present sea level rise rate and subsidence rate scenarios.

1. Introduction

Tidal wetlands and salt marshes are among the most productive ecosystems of the world (Bouchard and Lefeuvre, 2000; McLusky and Elliott, 2004). They provide many kinds of ecosystem services, such as coastal protection, nutrient cycling, carbon sequestration, climate regulation, recreation and nursery grounds for many fish and invertebrate species (Costanza et al., 1997; Allen, 2000; Gedan and Bertness, 2009; Barbier et al., 2011). At the same time tidal wetlands and salt marshes are some of the most vulnerable ecosystems on earth that show a rapid loss through land-use change, habitat conversion and coastal squeeze (Doody, 2004; Pendleton et al., 2012). In the future, accelerated sea level rise could potentially lead to further marsh losses, especially in combination with human activities that lead to increased subsidence rates or decreased sediment delivery (Kirwan and Megonigal, 2013).

Due to river damming and subsequent enhanced sedimentation within the river basin, sediment availability for marshes downstream in the coastal region has decreased in many areas worldwide (Sanchez-Arcilla et al., 1998; Stanley and Warne, 1998; Yang et al., 2005; Syvitski et al., 2009). Reduced sediment supply is the main cause for drowning of salt marshes in the Mississippi basin (Coleman et al., 1998). In the Yangtze estuary, the inflow of sediment has decreased dramatically because of the Three Gorges Dam leading to a noticeable slowdown in the expansion of salt marshes in the estuary (Yang et al., 2003). Decreasing suspended sediment concentrations are an important factor for the long-term vertical growth of marshes (Temmerman et al., 2003a).

The vertical accretion of a salt marsh is determined by sedimentation of mineral matter (sandy or clayey silts) and

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accumulation of organic matter. The mineral sedimentation process of salt marshes is largely correlated with the hydrodynamic conditions. Within a single marsh system the frequency, duration and height of inundation affect the inorganic sedimentation rate and thereby the accretion rate (Krone, 1987; French, 1993). Many empirical studies have identified these relationships (Pethick, 1981; Stoddart et al., 1989; De Jong et al., 1994; Temmerman et al., 2003b; Chmura and Hung, 2004; Detriche et al., 2011). Marsh growth was also modelled under different scenarios of sea level rise and sediment supply (Allen, 1990, 1995; French, 1993; Temmerman et al., 2003a; Kirwan and Murray, 2007).

Historical evidence shows that the extent of salt marshes in the Holocene was coupled tightly to the rate of sea level rise (Allen, 2000). Several papers have quantified the sedimentation rate in accordance with local sea level rise (French, 1993; Cundy and Croudace, 1996; Roman et al., 1997; Morris et al., 2002; Allen, 2003; Kirwan and Murray, 2008; Kirwan and Temmerman, 2009). In general, these studies demonstrate that biophysical feedbacks exist between plant growth and geomorphology that result in marshes to adjust towards equilibrium with sea level and that allow marsh vertical accretion to keep pace with high rates of sea level rise, provided sufficient sediment is available (Kirwan and Megonigal, 2013). Thus, sediment availability and delivery is an important boundary condition for the long-term fate of salt marshes.

This study focuses on long-term salt marsh vertical accretion in a system that experiences strongly reduced suspended sediment concentrations. The study was carried out in the Oosterschelde estuary, a tide-dominated mesotidal estuary in the southwest of the Netherlands (Fig. 1). After a major storm surge in 1953, the system was modified drastically in the 1980s. The modification included the construction of a storm surge barrier (1979–1986) at the sea side and two compartmentalization dams (Oesterdam, 1986, Philipsdam 1987) (1977–1987) in the inner part (Nienhuis and Smaal, 1994)(Fig. 1). As a result, tidal conditions changed and suspended sediment concentrations dropped drastically. Previous research in the period 1984–1992 observed a slowdown in accretion rates of the salt marshes in the Oosterschelde in the early 1990s, a few years after the finalization of the construction works (De Jong et al., 1994). These authors predicted a permanent reduction in vertical accretion rates on the salt marshes in the Oosterschelde as a result of the decrease in sediment supply (De Jong et al., 1994). In this paper, these predictions are evaluated using a long-term time-series of vertical accretion rates on three salt marshes in the Oosterschelde. The paper firstly addresses the spatial variation of vertical accretion within each marsh and among marshes and secondly evaluates the temporal trend of salt marsh accretion under the conditions of reduced sediment supply. Whether the salt marshes in the Oosterschelde are expected to survive under conditions of (projected) sea level rise is also discussed.

2. Material and methods

2.1. Study area

The history of the Oosterschelde estuary is characterized by an increasing isolation from the river influences. The estuary changed in the course of time from a turbid, coastal plain estuary into a tidal bay (Nienhuis and Smaal, 1994). As a consequence of the construction works in the 1980s, the tidal range in the Oosterschelde (Yerseke) was reduced by about 12% from 3.7 m to 3.25 m (Brinke, 1994) by 1987. The tidal channels are oversized but cannot be filled with sand derived from the outer tidal delta. They act as sinks for sediment eroded within the estuary from the intertidal flats and marshes (Mulder and Louters, 1994). Suspended sediment concentrations in the estuary have decreased drastically due to this extra sink for sand and mud in the deep channels and the strongly reduced currents (Nienhuis and Smaal, 1994). The suspended sediment concentration, comparing the mean value of 1980–1983 (pre-barrier) with that of 1989–1992 (post-barrier), dropped by 70%, 64%, 52% and 69% at Lodijkse Gat (LG), Roggenplaat (RG), Krabbenkreek (KK) and Zijpe (ZP) stations respectively (Fig. 2).

This study was carried out on the three largest salt marshes (Rattekaai, Sint Annaland and Slaak, Figs. 1 and 3 and Table 1), for which long-term monitoring accretion data are available. These three sites represent about 71% of the total salt marsh area in the Oosterschelde (De Jong and Van der Pluijm, 1994).

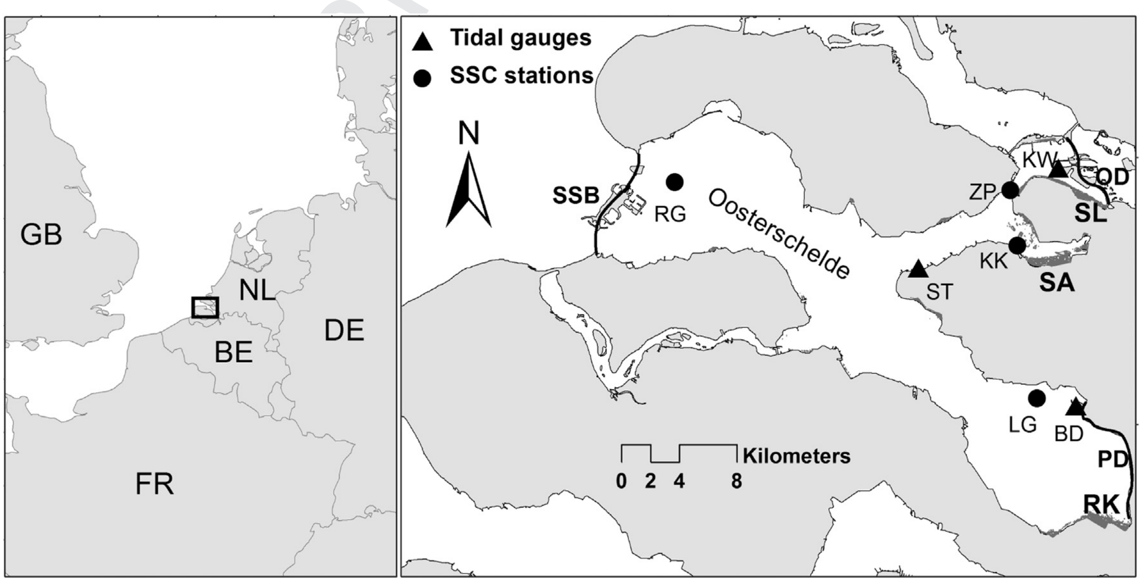

Fig. 1. The Oosterschelde estuary with the three studied salt marshes (RK: Rattekaai, SA: Sint-Annaland and SL: Slaak) indicated as dark grey area; the nearby tidal gauges (KW: Krammersluizen west, ST: Stavenisse and BD: Bergse Diepsluis west) as solid triangles, the suspended sediment concentration sampling stations (RG: Roggenplaat geul west, ZP: Zijpe, KK: Krabbenkreek and LG: Lodijkse gat) as solid circles and location of the Storm Surge Barrier (SSB), Oesterdam (OD) and Philipsdam (PD) as thick black lines. map source: base map of the Netherlands is from ESRI Data&Maps 9.3.1, vegetation maps from Rijkswaterstaat.