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Sand in the salt marsh: Contribution of high-energy conditions to salt-marsh accretion

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ABSTRACT

The environmental dynamics at barrier-island salt marshes are reflected in lateral and vertical textural patterns of the marsh sediment. During normal conditions, fine-grained sediment is deposited, whereas during high-energy conditions also sand accretion can occur. This paper describes the occurrence and importance of sand deposits for the building of salt marshes. The study was carried out in the Wadden Sea on the islands of Schiermonnikoog (NL), Terschelling (NL) and the peninsula of Skallingen (DK). Firstly, we recorded the presence of sand in the sediment representing initial salt-marsh formation. The results indicate that part of the salt marsh developed under conditions that were dynamically enough for sand to be transported. The spatial distribution of these conditions depends on soil elevation and location on the marsh, modified by the presence of artificial sand dikes. Further we recorded the presence and thickness of sand layers within the salt-marsh sediment. Sand layers are found on twenty percent of the marsh area and are partly associated with the local sources of the sand, i.e. marsh creeks, the salt-marsh edge and washovers. In total, sand layers contribute less than ten percent to the volume of marsh deposits on Schiermonnikoog. We dated the layers using the thickness of the deposits and known marsh age. The ages of the layers indicate that for the decadal occurrence of storms capable of depositing sand in the salt marsh, the local hydrodynamics and availability of sand determine whether a site receives sand or not.

1. Introduction

Coastal salt marshes are valuable for both biodiversity and coastal protection (e.g. Doody, 2008). They are situated at relatively sheltered places along the coast where sufficient fine-grained sediment is available. Nevertheless, as salt marshes are in direct contact with the sea, they experience a certain degree of dynamics of wind, waves and currents, resulting in variations in marsh extent and vertical growth. Salt marshes may form a protection for the hinterland by buffering these dynamics, but on the other hand if the dynamics become too large (e.g. with changes in climate and sea level) a salt marsh may drown. Knowledge on the natural dynamics of salt marshes is therefore essential for making decisions regarding the conservation of their specific ecosystems and biodiversity, coastal protection and island response to (global) sea-level rise.

The sediment of salt marshes, mainly mud, silt and organic material, reflects the sheltered conditions under which salt marshes generally develop. However, variations in energy conditions, for example from tidal and seasonal periodicity and the occurrence of storms and tsunamis, are reflected in the grain-size distribution of the deposited sediment (e.g. Allen, 2000). Consequently, salt marshes exhibit textural variations in a lateral direction as well as in the vertical stratigraphy (e.g. Wheeler et al., 1999; Allen and Haslett, 2002). During high-energy conditions, coarse-grained material, sand, may be deposited on the salt marsh (e.g. Stumpf, 1983; Ehlers et al., 1993; Roman et al., 1997; Wheeler et al., 1999). Because these events occur infrequently, their deposits form sand layers in the profile, forming records of the dynamics of the salt-marsh environment.

Storm-related coarse-grained layers and sand deposits may occur at various locations within a salt marsh, reflecting their sources and depositional processes (Fig. 1). Firstly, sand laminae are observed thinning out from the creek levees (Van Straaten, 1954). During overmarsh tide, the velocity of the flooding waters decreases as the result of lateral spreading from the creek and drag from vegetation on the creek banks. This reduces the sediment-carrying capacity of the floodwaters and the coarsest sediment, sand, is deposited. Secondly, sand layers are observed along the salt-marsh edge, sometimes taking

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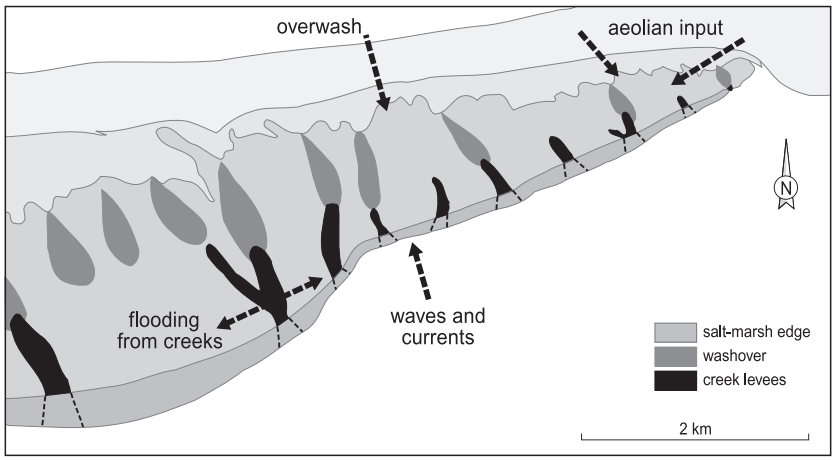

Fig. 1. Schematic representation of the expected dominant sand deposits and the responsible processes for the salt marsh of Schiermonnikoog, the Netherlands.

the form of ridges that follow the salt-marsh edge or cliff (Van Straaten, 1954; Ehlers, 1988; Ehlers et al., 1993; Eisma and Dijkema, 1997; Ward et al., 1998; Wheeler et al., 1999). The sand is deposited when the marsh vegetation dampens waves and currents that eroded sand from the intertidal flats (Bartholdy, 1997; Möller et al., 1999; Neumeier and Amos, 2006). As sedimentation rates along the marsh edge are generally high, variations in dynamics will be clearly recorded in the form of distinct layers (Allen, 2000). If a salt marsh advances in cyclic growth, relict edges with their associated layering may remain in the landscape (Wheeler et al., 1999; Van de Koppel et al., 2005; Pedersen and Bartholdy, 2007; Van der Wal et al., 2008; Chauhan, 2009). Thirdly, sand layers on barrier-connected salt marshes may be the result of overwash (e.g. Ehlers et al., 1993; Warren and Niering, 1993; Flemming and Davis, 1994; Oost and De Boer, 1994; Donnelly et al., 2001; Nielsen and Nielsen, 2006; Boldt et al., 2010). During these conditions, the marsh is not only inundated from the back-barrier area, but also from the open sea through gaps in the dunes. The eroded sediment from the beach and dunes is deposited in the form of a washover fan. Finally, aeolian transport may add sand to the salt marsh (French and Spencer, 1993; Neuhaus, 1994; Reineck and Gerdes, 1996). Sources are dunes, washover deposits, beach and beach plains. Additionally, two not-storm related processes that may deposit sand on the salt marsh are ice rafting (Van Proosdij et al., 2006) and tsunamis (e.g. Morton et al., 2007; Komatsubara et al., 2008).

Most studies only mention sand layers from one of the above marsh locations, whereas in principle a single salt marsh could contain sand layers from all sources. And even though in allochthonous marshes coarse-grained deposits from high-energy events are less important for salt-marsh building than the deposition of clays and silts (Wheeler et al., 1999), their relative contribution is not known. This leads to the question of what the spatial distribution of sand deposits within a salt marsh looks like, and what this tells about the environmental conditions and their effect on salt-marsh development. And what is exactly the importance of sand for salt-marsh accretion?

The ongoing research on salt-marsh ecology at the University of Groningen has produced a large database of soil cores from the Frisian Islands, mainly from the barrier-island salt marsh of Schiermonnikoog, The Netherlands (e.g. Olff et al., 1997; Van Wijnen and Bakker, 2001). This dataset provides a unique opportunity to study the temporal and spatial development of salt marshes and answer questions such as the ones posed above. The purpose of this study is to create an overview of the spatial and temporal aspects of sand deposits in salt marshes, and relate this to the process of salt-marsh development. Firstly, we will record the importance of sand during the initial stage of salt-marsh formation. Secondly, we describe the occurrence of layers within the marsh deposits and date these deposits using the available data of marsh age and net accretion. We will describe the patterns on the scale of the entire marsh and subsequently zoom in on selected locations to identify the sources of the sand.

2. Methods

2.1. Study sites

The main study area is the Dutch barrier island of Schiermonnikoog (Fig. 2). Additional measurements were done on Terschelling (NL) and Skallingen (DK). The studied marshes are all barrier-island salt marshes in the southern North Sea. Such marshes develop when newly-formed dunes shelter an area from flooding from the open sea. The salt marsh itself consists of a vegetated layer of fine-grained sediment, which we call the top layer. It is mainly mineral sediment with a median grain size in the silt or very fine sand fraction. It overlies what once were the intertidal flats, beach plain and lowest part of dunes. This sand surface (the base layer, with the median grain size in the fine sand fraction) generally slopes down from the dune foot towards the intertidal flats, and the marsh surface largely follows this inherited topography (De Leeuw et al., 1993).

The barrier island of Schiermonnikoog (53°30′N, 6°10′E) is located in the Dutch Wadden Sea. The tidal range is 2.3 m and Mean High Tide (MHT) is around 1.00 m + NAP (where NAP is the local ordnance datum representing mean sea level). The main salt-marsh complex of Schiermonnikoog is located at the eastern part of the island and is 8 km in length and 0.5–1.5 km in width (Fig. 2A). It is drained by several large creeks, oriented roughly north–south (Fig. 2E). The intertidal flats bordering the salt marsh are dominated by relatively sandy sediment. Some of these creeks are connected to overwash channels (Oost and De Boer, 1994; Ten Haaf and Buijs, 2008). The average net surface elevation change ranges from 0.1 to 0.5 cm a^{-1} (with extremes of 1.1 cm a^{-1} in the pioneer zone) and depends on marsh age and base elevation (Van Wijnen and Bakker, 2001). The island of Schiermonnikoog has been extending eastward and southward, resulting in gradual new marsh formation. Consequently the marsh exhibits a chronosequence: marsh age decreases from approximately 200 year-old in the middle of the island towards very young at the eastern end. Average top-layer thickness varies accordingly (Olff et al., 1997). In 1959 a sand dike was built that cut off a large part of the beach plain from the North Sea. The sand dike extended 5.5 km from west to east and strongly facilitated the growth