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Erosion of an intertidal mussel bed by ice- and wave-action

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ABSTRACT

The persistence of intertidal mussel beds is governed by both biotic and abiotic processes. Many studies have shown that waves and currents are able to erode mussels from an intertidal mussel bed, but here it is demonstrated that in temperate regions ice action can be important as well. These findings result from a 27-month-long monitoring campaign on a mature intertidal mussel bed in the Dutch Wadden Sea. Daily camera observations revealed two periods in which significant erosion occurred. The first event occurred in a period during which the bed was covered by ice. Ice action resulted in an initial decrease of 19% in mussel covered area around the monitoring station. The losses were concentrated in three erosion hotspots of which the largest two were located close to the beds' edge. Around these hotspots, up to 0.3 m high ridges of piled up mussels had formed, with the highest ridges located westward of these erosion gaps. The observed topographic changes support the view that the mechanism by which the bed was damaged was, at least partly, due to physical disturbance by scouring ice. Recovery of mussel cover was limited in the 19 months following the ice action event. Due to sedimentation and reorganization of the mussels, initial relief inside the mussel bed was reduced again and mussels spread out over a larger area. Height differences between uncovered parts and mussel covered parts increased as a result of sedimentation in mussel covered areas. Wave action during a storm period caused a further reduction in mussel cover. Especially areas that were previously elevated by ice action suffered from large losses. Wave erosion occurred during multiple wind events, causing initially small erosion gaps to expand outward and increase in extent. The results suggest a twofold impact of wave and ice action on mussel bed cover: firstly, by directly eroding mussels from mussel beds; secondly, by indirectly increasing the exposure of mussel beds to wave induced bed shear stresses.

1. Introduction

Intertidal mussels are considered as a key species in the ecosystem of the Dutch Wadden Sea. Therefore, several programs exist to protect and increase the area covered by intertidal mussel beds. Most often, these mussel bed restoration plans rely on habitat suitability maps (i.e. Brinkman et al., 2002). However, to be able to create these maps knowledge on the processes determining mussel bed growth and erosion is required. The most important factors that determine mussel bed persistence are predation (Zwarts and Drent, 1981; Dankers and Zuidema, 1995), erosion of mussel beds by hydrodynamic forcing (Widdows et al., 2002), food availability (Seed and Suchanek, 1992) and the presence of a suitable substrate (Mcgrorty et al., 1993). This study focuses on erosion by wave action and a less well documented and less frequent process of erosion, namely erosion by ice action.

Mussel beds are considered to be long-lived biogenic structures. Mussel beds slowly deteriorate and may disappear if no new spatfall occurs (Essink et al., 2005). The reduction of the mussel bed is caused by predation and erosional processes. Storms have been reported to erode mussels beds (Nehls and Thiel, 1993). Mussels protect themselves from erosion by attaching to the underlying substrate or to conspecifics. Solid substrates are widely available for mussels living on rocky shores. However, they are absent in soft-sediment intertidal areas such as the Dutch Wadden Sea. Therefore, mussels mainly attach themselves to each other, but also to other shellfish and to shell debris in the sediment (wa Kangeri et al., 2014). As the underlying substrate is unstable local erosion or deposition can occur. By repositioning, themselves mussels adapt themselves to these changing conditions. Mussels promote local deposition of suspended sediment when filtering the water column for food. Especially when the mussels are young they can reposition themselves quickly, a height increase of 6 cm over the course of a day has been observed by Widdows et al. (2002).

Waves and currents influence soft-sediment intertidal areas on two different time-scales (Balke et al., 2011). On the short time-scale (hours to days) storm conditions result in increased wave

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heights and enhanced flow velocities. The resulting increased bed shear stresses enhance the erosion probability of the mussels (Widdows et al., 2002). On the longer time-scales (~ years), hydrodynamic processes influence the local erosion and sedimentation trends of the substrate. Both erosion and sedimentation can threaten the persistence chances of mussel beds, for example by affecting the substrate characteristics. Deposition of sediment can negatively impact immersion times, thereby limiting the food intake while simultaneously increasing the predation time for birds (Brinkman et al., 2002). Furthermore, a change in local mussel bed topography likely influences the exposure of the bed to waves and currents. Vice versa, the impact of the physical factors partly depends on the physical and ecological conditions of the mussels, for example due to seasonal effects (Price, 1980, 1982; Carrington, 2002; Moeser et al., 2006). The attachment strength is usually lowest during fall due to reproduction. It increases slowly over winter and early spring. Reduced attachment strength reduces the bed's resistance against erosion (wa Kangeri et al., 2014).

On top of waves and currents, occasionally ice formation and ice action have been found to erode mussel beds. Drifting ice can move sediment in the intertidal zone (Dionne, 1984; Pejrup and Andersen, 2000). As was shown by Dionne (1988), the scouring effects of ice are largest in the temperate regions (between 48° and 65° Northern latitude). However, in these regions, ice cover is a rather unpredictable event and therefore no direct measurements are commonly available. Ice scour tracks on mussel beds have been observed in the Danish and German parts of the Wadden Sea by Obert and Michaelis (1991) and Strasser et al. (2001), respectively. A similar damage by ice scour to benthic communities has been observed in the Canadian High Artic by Conlan et al. (1998). Ice scour was identified by Strasser et al. (2001) to be a significant factor causing a reduction in size or even disappearance of mussel beds. A second mechanism by which ice erodes mussel beds is by the development of ice in small ponds inside the mussel bed. At low tide the remaining water freezes and the ice attaches to the mussels. When the water level rises again an upward buoyant forcing arises (Denny et al., 2011). When the ice starts to float mussels frozen in the ice are detached from the substrate, destroying the mussel bed.

The aim of this study is to determine the impact of erosional agents on an intertidal mussel bed and to study the mechanisms of erosion. This paper reports and discusses the effects of ice and wave-action on mussel coverage and topography of an intertidal mussel bed. To monitor the long term mussel bed evolution a video camera system was used to observe the evolution of a mature mussel bed. Coincidently, early during a 27-month-long

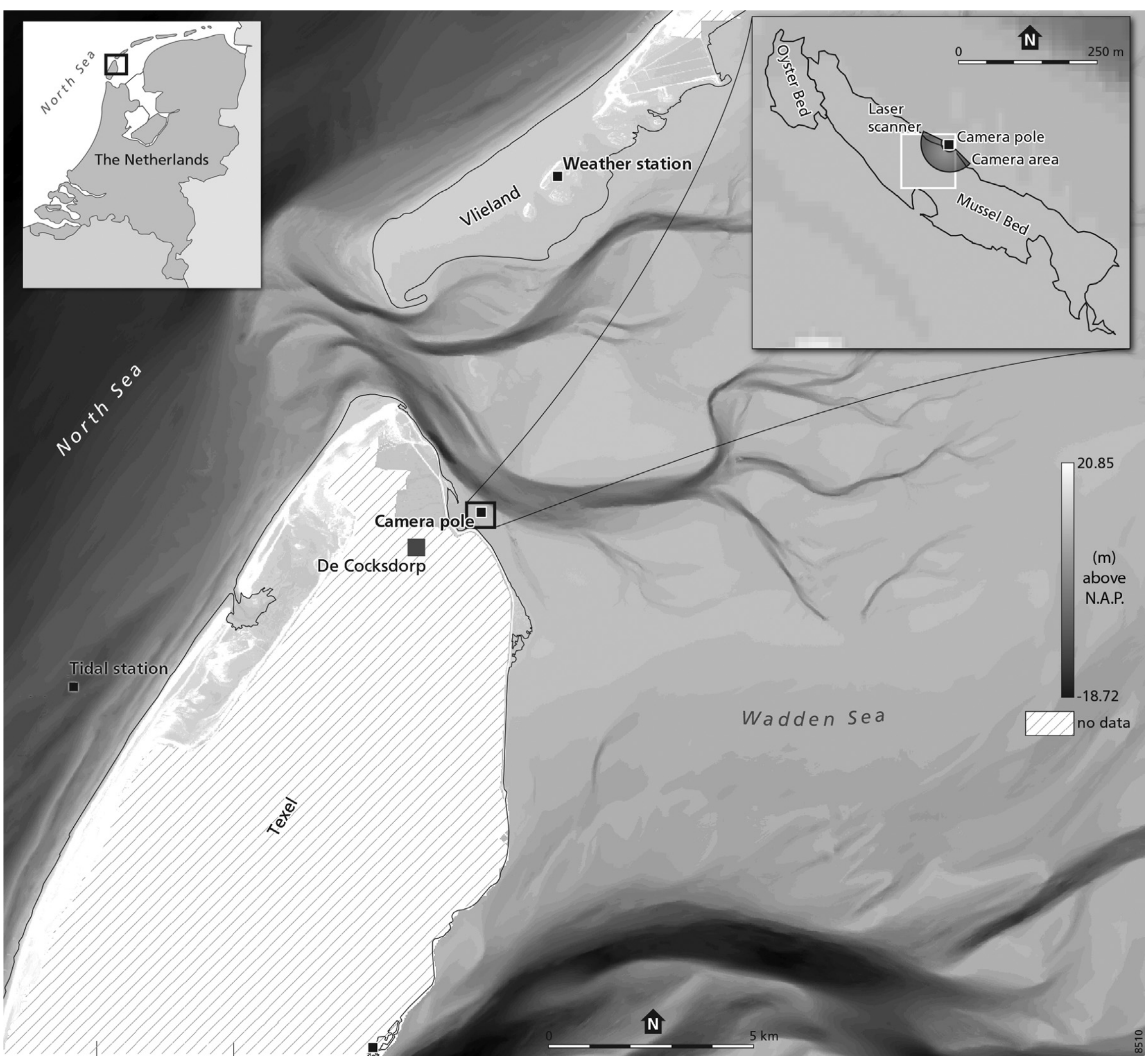

Fig. 1. Bathymetric map of the area surrounding the measurement site. Location of the research area and the tidal and Weather station are marked. In the top left a map of the Netherlands is shown where the area covered by the bathymetric map is outlined. In the top right corner the contour of the monitored mussel bed is shown together with the research areas covered by the camera system and the laser scanner.