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EXPERIMENTAL INVESTIGATION OF COASTAL FOREDUNE EROSION

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1 INTRODUCTION

Low lying coastal foredunes can provide an initial buffer against near-shore wave attack, while higher elevated dunes can form a sheltering barrier against flooding of an adjacent hinterland (Temmerman et al. 2013). The Eiderstedt peninsula in Northern Germany harbors a dune system spanning roughly 8 km in north-south direction, consisting of an up to 2 km wide beach, lined by an elongated foredune of varying dune dimensions (Mehrtens et al. 2023). An established secondary dune chain closes a 1.2 km gap in the local dike system (see Fig. 1a and 1b). This work presents novel large-scale experiments on the influence of a foredune in front of a secondary dune during storm surge situations. Working hypothesis is that the foredune acts as a sediment buffer, damping incoming waves and reducing overall erosion on the main dune.

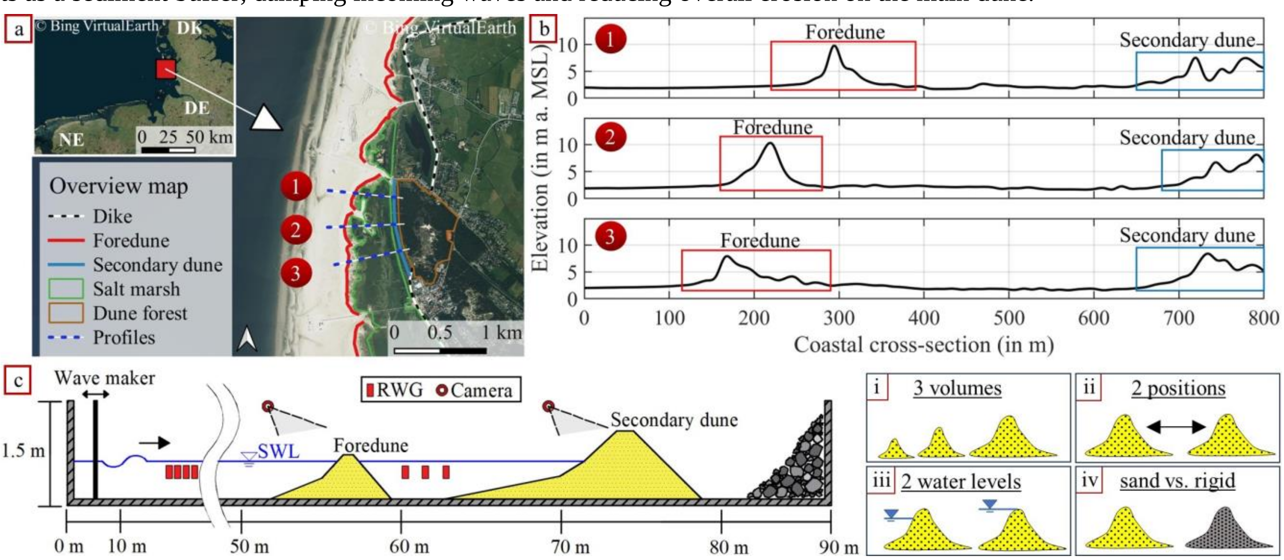

Figure 1: Study area at the Eiderstedt peninsula with three exemplary cross-section profiles (above) and schematic experimental model setup including all tested foredune conditions (below).

2 METHODS

Physical experiments with various foredune models and an adjacent secondary dune model (volume of V = 3.89 m³) (see Fig. 1c) were conducted in a wave flume at the Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Germany. Apart from the sediment grain size d_{50} of 0.127 mm, the model setup including hydrodynamic conditions followed

Froude's similarity law with a length scale factor of λ = 7. Several test runs were performed covering the following conditions: (i) three foredune volumes (V_{low} = 0.96 m³, V_{medium} = 1.67 m³, V_{high} = 2.65 m³); (ii) two foredune locations (directly at the secondary dune toe and 5 m seaward of the dune toe); (iii) two still water levels (d = 50 cm and d = 56 cm) with same wave conditions (JONSWAP spectrum with H_s = 18 cm and T_p = 2.8 s); (iv) wooden foredune models to simulate rigid structures. Each test was split into four wave bursts of 10 min, 20 min, 30 min and 53 min, giving a total test duration of 113 min. After each wave burst, both dune profiles were scanned along the center line using a mechanical measuring gauge. The flume was equipped with a wave gauge array including four resistive wave gauges (RWGs) to control incident wave conditions in front of the foredune as well as three RWGs in the intermediate section between both dunes to record changes in wave field.

3 RESULTS

Experimental results for the reference case with no foredune (see Fig. 2a) show a significant dune erosion over the entire test duration. Eroded material from the crest is deposited on the slip side of the dune within the swash zone. Fig. 2b and 2c show the addition of two foredune geometries at the locations examined. In both cases, the entire foredune crest erodes after the first wave burst of 10 min as a consequence of extensive overwash. Throughout the remaining test duration, the foredune widens marginally in both directions due to ongoing wave action, causing a loss in dune height. Compared to the reference test, the secondary dunes exhibit less erosion by the end (see respective erosion volumes in Fig. 2f). In contrast, the crest of a high foredune does not erode completely after the first wave bursts (see Fig. 2d), but instead towards the end of the test period. As a result, distinct erosion development is almost confined to the foredune, whereas the secondary dune exhibits only minor profile erosion at the end with significantly lower erosion volume (see Fig. 2f). During the final test series, a low rigid foredune (see Fig. 2e) dissipates incoming wave energy similar to a submerged wave breaker. In turn, the secondary dune shows less erosion compared to the low foredune (see Fig. 2b).

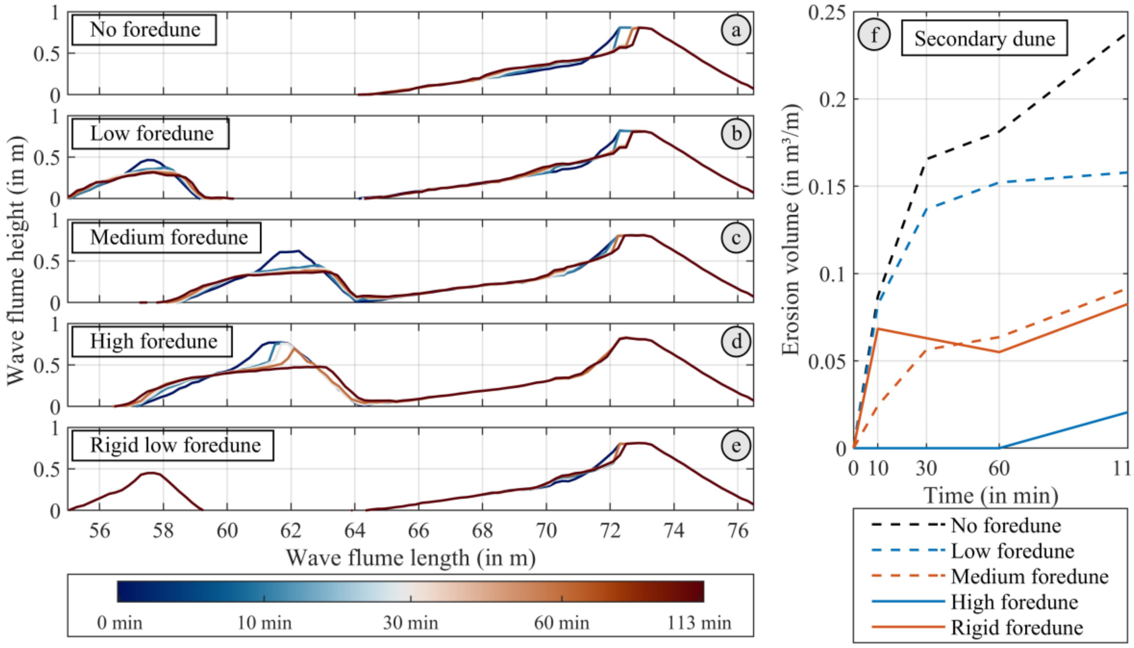

Figure 2: Profile development of the foredune and secondary dune for exemplary model setups with d = 0.5 m (left) and resulting temporal dune erosion at the secondary dune (right).

4 DISCUSSION

The experimental results show the significant influence of a foredune on the erosion behavior at a secondary dune; these settings have been entirely overlooked in the pertinent literature. Overall, the presence of a foredune reduced the erosion volume at the secondary dune in all tests. Although all foredunes were commonly overwashed and eroded, their remaining residual profiles still provide a protective effect as incoming waves break at greater distances from the secondary dune, causing reduced wave runup and erosion at the secondary dune.

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