MODELED INFLUENCE OF LARGE-SCALE TREE COVER ON THE EROSION PROCESS OF COASTAL DUNES

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INTRODUCTION

Vegetated coastal dunes are a common landform along sandy coastlines worldwide which often provide essential contributions to coastal protection. In the context of climate change and sea level rise, it becomes more relevant for established dune systems to ensure a sufficient level of protection for adjacent communities and infrastructure (Mehrtens et al., 2023). During storm surges, extreme water level and wave attack cause severe dune erosion while overtopping may potentially lead to destabilization and failure. Established coastal dune forests -previously overlooked- have recently gained increasing scientific attention in this context, as they can cover extensive dune systems, either leading to stabilizing or de-stabilizing effects on the dune erosion process when subjected to storm surges. Which tendency of trees falling into the active erosive zone prevails is currently subject to speculations, as hard scientific evidence is entirely lacking. Established coastal dunes often are covered by coniferous forest like plantations adopted several centuries ago to halt aeolian sediment transport into adjacent farm and housing areas (Hofstede, 1997). Recent experimental studies on the influence of marram grass coverage on erosion resistance indicated that vegetation may not only provide erosion resistance, but may also play a pivotal role in exacerbating storm induced erosion (Feagin et al., 2023). Some studies based on field measurements and physical experiments have looked at the influence of different vegetation covers on coastal dune erosion. Although these investigations considered a range of vegetation species, relatively few focus on trees such as black pines and their potential impact on dune resistance under wave attack. A specific strand of research covers the effects of needle-tree forests, sometimes combined with dune geometries when subjected to tsunami loading (Tanaka et al., 2014).

Since it is difficult to estimate specific parameter for complex branch structures (Kalloe et al., 2022), physical experiments require a proper scaling and modeling under controllable conditions. Kobayashi et al. (2013) conducted initial laboratory tests using cylindrical wooden dowels as substitute models for woody plants. Although they observed reduced scarping and overtopping for dunes with wide woody vegetation covers, they recommended further large-scale experiments in order to consider additional influencing factors (specific diameter, height, spacing, alignment, burial depth).

OBJECTIVES AND NOVELTY

The novel aspect of this study is to present Froude scaled experimental research where dune-tree models are tested and multiple forest configurations are employed to extend the current understanding of the underlying, relevant physical processes of dune erosion dynamics in a wave-loading regime.

METHODOLOGY

Based on the coastal dune system of Sankt Peter-Ording, Germany physical model experiments are currently conducted in a medium-size wave flume (dimensions: L x W x H = 90 x 2 x 1.5 m). The dune system comprises a 16.5 m high grey dune covering 0.55 km² and acting as natural flood protection. An established pine forest planted in 1864 (Weber et al., 2023) covers 61% of the grey dune area (see Fig. 1).

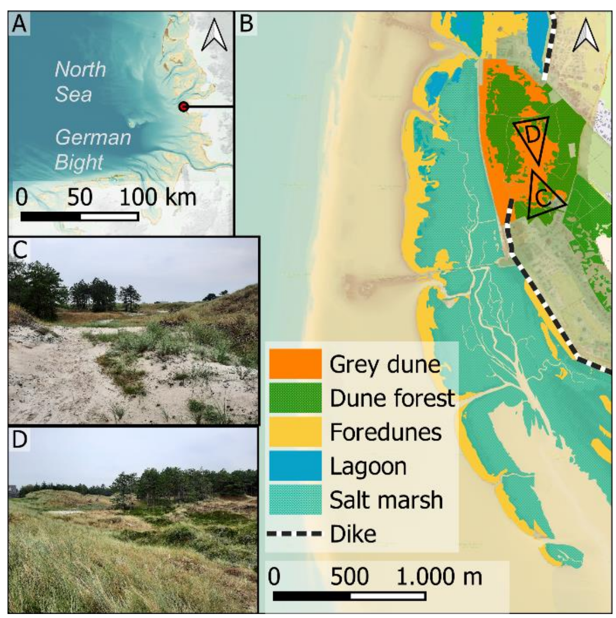

Fig. 1 - A German Bight with location of the dune complex; B Overview map of the dune system with the grey dune area and forest cover mapped; C-D pictures of the pine forest cover on the grey dune, 2022.

The experiments comprise two basic dune setups, (i) a reference dune entirely composed of sand and (ii) a sand dune with different configurations of surrogate tree models with variations of tree specimen counts, spacing, location within the dune and burial depths. The tree models represent mountain pines (lat.: *Pinus mugo*) and are fabricated using wood for the stem part and innovative 3D resin printing techniques to create complex branch and needle structures. Subterranean root structures are approximated using wooden disks as well as root structures created with 3D resin printing. 3D model data for creating both branch-needle and root-complex structures are obtained from life tree specimen at the focus region. Individual trees are removed in collaboration with the local forestry department in Sankt Peter-Ording, Germany. Branches and roots are then scanned using LiDAR and structure from motion techniques. Original trees feature a growth height of 3-4 m in wide stretches and 5-6 m in small patches. Trunk diameters measure 20-25 cm at breast height, with a root depth of approximately 1-1.5 m. Applying Froude's similarity law, the tree models scaled at 1:7 stand 0.5 m tall above ground and sprout multiple branches modeled after scanned data. Subterranean model parts consist of a 0.15 geotropic tap root and lateral roots of first order, which grow horizontally and are simulated as well. Third order rhizomes are not yet included in the model, as the resolution of the 3D printer does not allow to resolve those at the moment. Forest cover density is modeled according to site specific degree of tillering ranging from D_t = 0.7-0.8 (medium to densely populated) (Scheffler, 2023) resulting in multiple rows of equidistantly spaced tree models 30 cm apart arranged in a staggered configuration (see Figure 2).

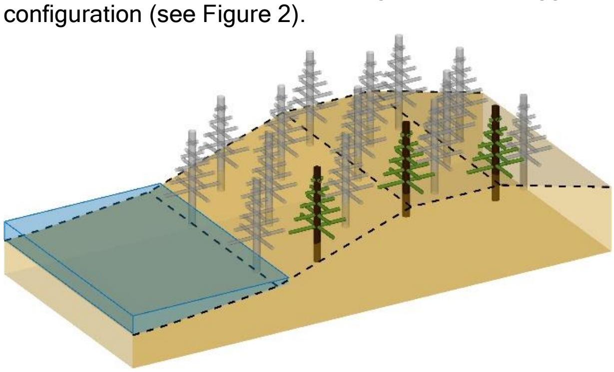

Figure 2 - Dune forest model setup with staggered array of equidistantly spaced tree models on the 1:7 dune profile. Scaled tree models have a branch structure including foliage and root system parts for erosion resistance.

Apart from the sediment size, the dune model followed Froude's similarity law with a length scale factor of 7. A total of two different water depths h = 50 cm and 56 cm are used. Every test is conducted, using irregular waves (JONSWAP spectra with γ = 3.3) and split in two wave bursts with varying wave parameter (H_s = 14 - 18 cm and T_p = 2.3 - 2.8 s) and a respective duration of 113 min to investigate the influence of two consecutive storm surges. Several wave gauges are installed along the wave flume to measure water surface elevations and separate incoming and reflected waves. The dune profile is recorded during each test through an observation window in the flume wall to capture wave-dune-tree interactions. Furthermore, two novel solid-state 3D Lidar sensors are installed on either side of the dune to track the dune profile as well as potential tree movements over time at a sampling frequency of 0.7 Hz. The initial cross-shore dune profile (illustrated in Fig. 3) is identical for both experiment lines and made of fine, non-cohesive, well sorted sand with a characteristic grain size of d_{50} = 0.144 mm.

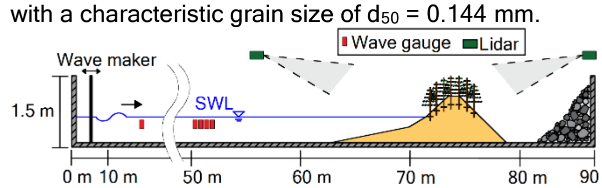

Figure 3 - Overview of physical experimental dune-tree model setup in the wave flume.

PRELIMINARY RESULTS

At this stage, the measurement program of the reference tests with the sand dune is already completed (covering a total of 12 tests with at least one repetition per setup). First results shown in Fig. 4 already demonstrate that characteristic erosion behavior of the dune can be assessed at high spatial and temporal resolution using the chosen measurement techniques.

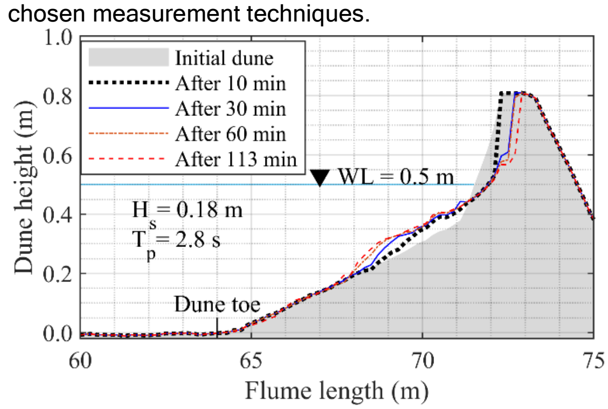

Fig. 4 - Exemplary 2D dune profile evolution for the reference dune without tree surrogates from initial profile to eroded state after 113 min under collision regime.

Predominant erosion processes observed during experiments without tree models pertain to notching and subsequent overhang slip offs. Eroded material is deposited in front of the dune, subsequently reducing the incoming wave energy.

DISCUSSION & OUTLOOK

The novel character of the experiments allows to investigate specific erosion mechanisms described by Erikson et al. (2007). Hydrodynamic load variations will facilitate impact regime (collision/overwash/breaching) assessment described by Sallenger (2000). Integrating detailed tree models into the dune setup, the relative impact on erosion under identical loads can be quantified. Results will yield valuable insights into physical behavior of dunes with forest vegetation to assess a potential flood protection contribution.

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Due to space limitations, references mentioned herein were not provided.

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