EXPLORING THE LONG-TERM IMPACT OF BEACH ENTRANCES ON DUNE DEVELOPMENT

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INTRODUCTION

Beaches and coastal dunes offer many recreational opportunities and attract numerous visitors worldwide. In recent decades, the economic importance and intensity of human activities in beach-dune systems have increased, amplifying human impact on the system dynamics. Human activities can disrupt natural morphological development, affecting the natural sand transport by the wind or the vegetation development. Even low-intensity activities such as walking on the beach can contribute to the deterioration of vegetation and the early phases of dune formation (Jackson & Nordstrom, 2011).

While isolated effects of human-induced impacts have received attention in previous studies, the understanding of the long-term interactions between biophysical systems and human activities remains limited. The long-term effect of the interactions may affect the development of dunes and consequently compromise the expected functions of flood protection and enhanced spatial quality of the beach-dune systems.

Cellular automata (CA) modeling is a powerful tool for simulating dune emergence through interactions of different dynamics. In particular, the DuBeVeg (Dune-Beach-Vegetation) model is a CA model specifically designed to study the bio-geomorphological evolution of beach-dune systems, including aeolian, hydro- and vegetation dynamics (Keijsers et al., 2016). The rule-based approach of DuBeVeg allows for a flexible integration of human activities into the model.

An extension of DuBeVeg was developed to incorporate the influences of beach user walking activity associated to beach entrances, considering the effects on aeolian sand transport and vegetation growth. This study shows the extended model's capacity to reproduce the effects of entrances on dune development, allowing the exploration of the long-term effects of beach entrances on dune development.

METHODS

DuBeVeg employs a stochastic approach to model aeolian sediment transport. The topography of the beach-dune system is divided into unit sand slabs that are stochastically picked up and deposited downwind. This stochastic transport of slabs depends on specific model parameters, such as the bare dry sand probabilities of erosion (p_{e0}) and deposition (p_{d0}), which are constant across the entire surface and representative of sand composition. Furthermore, the transport of slabs takes into account factors like elevation with respect to the groundwater table and vegetation surface cover. The model accommodates changes in vegetation cover over time, reflecting the dynamic processes of vegetation growth and reduction due to erosion, sedimentation, and hydrodynamic influences. In addition, there is a probability for vegetation emergence in previously bare cells (Galiforni-Silva et al., 2019; Keijsers et al., 2016; Teixeira et al., 2023).

In the model extension, the human-induced effects of beach walking are integrated as alterations in p_{e0} and p_{d0}, as well as modifications in the vegetation growth functions and the probabilities of new vegetation establishment in bare cells. The influence zone of beach entrances and the associated reduction rates of p_{e0}, p_{d0}, and vegetation rules are determined based on comprehensive observations and quantifications of the impacts on vegetation and dune emergence at various locations along the Dutch coast. The derivation of these factors involves a detailed investigation of beach user trails (Bakhshianlamouki et al., 2023) and the translation of findings from experiments on planted vegetation (van Rosmalen et al., 2023). The revised probabilities and vegetation rules will be validated through a 10-year simulation of the Sand Motor, a large-scale nourishment located at the Dutch coast. The focus is on the southwest section of the Sand Motor, characterized by a widening beach and ample space for dune development. The validation process involves comparing the observed and simulated trends of the development of the beach-dune system. The extension and validation of the model are still ongoing.

The validated and expanded model will be employed to simulate long-term scenarios, incorporating various beach entrances. These simulations aim to assess the long-term impact of interactions between the human activities at beach entrances and the biophysical dynamics represented in DuBeVeg. In this study, we present the preliminary simulation results of two simple scenarios, a first scenario without entrances and a second scenario considering a single entrance.

RESULTS

Preliminary simulation results replicated the observed impacts of beach entrances on dune development.

These include the absence of dune emergence along a pathway in front of the entrance, with slightly reduced dune emergence in the vicinity of the path on both sides (Figure 1 and Figure 2b).

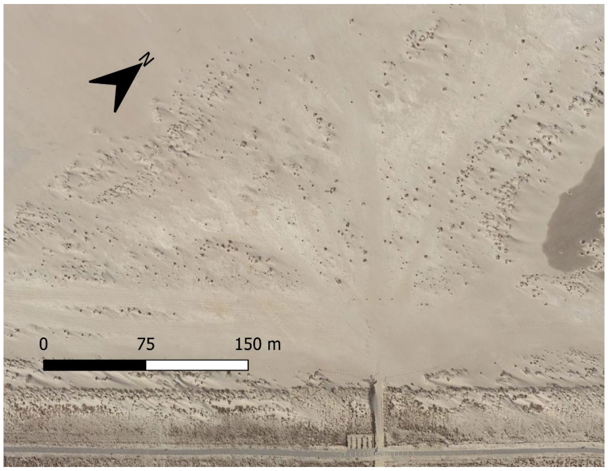

Figure 1 – Satellite image showing the effects of a beach entrance on incipient dunes. For an entrance located at the Sand Motor beach at the Dutch coast. Image obtained from Google Earth

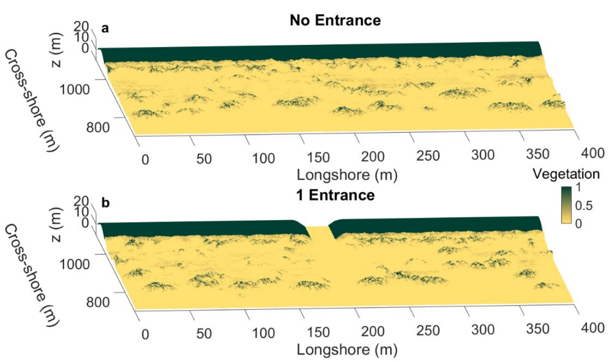

Figure 2 – DuBeVeg simulation after 20 years for (a) a scenario without considering any beach entrance and (b) a scenario considering one beach entrance.

The preliminary results further demonstrated the model's capacity to capture differences between the two simple long-term scenarios modeled. To quantify the differences, the percentage of area covered with vegetation was calculated, considering it as an indicator of the evolution of the size of the dune area. This percentage was calculated across a 200 m longshore stretch centered around the beach entrance, including the initially vegetated foredune (Figure 3). The total dune volume evolution was also calculated, defined as the volume above a pre-defined dune foot of 5 m + MSL. Volume changes from the initial dune volume are presented, also for a 200 m longshore stretch centered around the beach entrance (Figure 4). The calculated volumes included both new dunes that emerge on the beach and the initial foredune row.

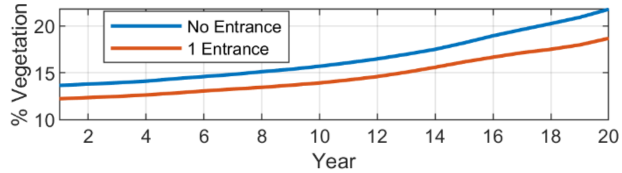

Figure 3 – 20-year evolution of the vegetated area for the two scenarios of Figure 2. Result shown for a longshore stretch of 200 m centered around the entrance.

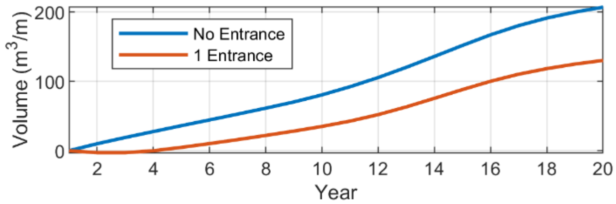

Figure 4 – 20-year evolution of the beach volume for the two scenarios of Figure 2. Result shown for a longshore stretch of 200 m centered around the entrance.

OUTLOOK

The initial findings from the simplified scenarios, which contrast the effects of no human impact with a situation involving a single beach entrance, demonstrate the model's capability to simulate diverse long-term trends, and quantify the human-induced impacts on beach-dune systems. Expanding the model to include additional entrances will be useful in providing coastal managers with insights into the long-term consequences of their planning decisions. The extended DuBeVeg model is promising for advancing our understanding of human-induced impacts on emerging dune morphology. The model's flexibility allows to further consider other human-induced impacts, such as the impacts of driving on the beach or the introduction of structures such as restaurants or fences.

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