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Evaluation of emerging behaviours on anthropogenic shores with a cellular automata model

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ABSTRACT

This study aims to develop a model to explore the emerging morphological development of anthropogenic shores. We extended an existing Cellular Automata model for the combined development of Dunes, Beaches and Vegetation (DuBeVeg) by including longshore sediment transport and coastline retreat, sand armouring of the beach, and the formation of beach scarps due to wave action. These processes were combined with aeolian, hydrodynamic, groundwater, and vegetation dynamics that were already represented in the model. The extended model was evaluated for a schematized version of the Sand Motor, a mega-nourishment in front of the Dutch coast. The simulated scale and types of dunes compared well with the real dunes that have developed on the Sand Motor since its construction in 2011. These preliminary results show that the extended model can represent the development of mega-nourishments realistically and can be used to assess the goals of such anthropogenic shores for different configurations and scenarios.

1. Introduction

Nature-based solutions have been applied at sandy coastlines for several decades, by continued sand nourishments for maintaining coastal flood protection. This is especially the case in The Netherlands, where it has been national policy to maintain beaches and dunes by regular sand nourishments. Recently, the scale of sand nourishments has been upscaled by several orders of magnitude, significantly modifying the original coastal landscape (i.e. creating Anthropogenic Shores (AS)). Examples of such mega nourishments are the Sand Motor and Hondsbossche Dunes at the Dutch coast. Cellular Automata (CA) models are a promising tool to study the beach-dune morphology that emerges at such mega-nourishments from the combined effects of aeolian processes, hydrodynamics, groundwater dynamics and vegetation dynamics, as well as the biophysical interactions between these processes. However, a realistic representation of the development of mega-nourishments with CA models is not yet available as some relevant physical processes for AS have not been incorporated yet in CA.

2. Methodology

The Sand Motor (SM) (de Vriend et al., 2014; Stive et al., 2013) is used as a case study for the extension of the DuBeVeg model to simulate the development of this AS over its first decade after construction. The SM is an example of an AS where the coastal landscape was significantly changed by a one-off local mega-nourishment. The SM is a feeder-type nourishment, forming a temporary coastal feature that will evolve freely and will disappear over time while feeding the adjacent coastline and dunes through natural sand transport processes.

The DuBeVeg model needed adaptation for its application to AS. In previous implementations of DuBeVeg, the beach was considered in an equilibrium state. Therefore, longshore variations of the beach morphology were not considered. However, AS are characterized by a non-equilibrium planform shape and a longshore variability of the morphology. To include this longshore variability and to simulate shoreline retreat of mega-nourishments, the analytical solution of the Pelnard-Considere diffusion equation was integrated in DuBeVeg (Arriaga et al., 2017). This equation imposes shoreline diffusion according to a Gaussian function, following the observed evolution of the shoreline of the SM (Roest et al., 2021). The diffusion rate of the shoreline varies with time depending on the initial shoreline shape and the diffusion coefficient. The diffusion coefficient depends on the local wave climate and the depth of closure, for this model we used the observed diffusion coefficient for the SM of 0.022 m^2/s (Arriaga et al., 2017).

Another process relevant for the development of AS but not yet considered in DuBeVeg is scarp formation of elevated nourishments. Scarps are formed in the cross-shore direction because of the steep slope of the newly created beach profile and the elevated height of the berm. Ongoing wave dynamics erode the seaward side, causing a vertical difference between the eroding shoreface (now at mean sea level) and the high berm. Scarps are observed at the SM during summer conditions, when wave conditions are mild. These scarps are eroded in winter due to increased storm surges (van Bemmelen et al., 2020). Scarp formation was represented in DuBeVeg by lowering the cross-shore profile below surge levels with an equilibrium profile that is less steep than the angle of repose. Then, a vertical scarp results from the connection between the remaining berm and the eroding shoreface. The angle of repose determines the final shape of the scarp.

Lastly, the use of an offshore sand supply for mega-nourishments is relevant for the aeolian dynamics. Coarser shell material in the nourished sand gets exposed when the finer sand is transported away, forming an armoured layer at the surface of the mega-nourishment. This armouring was included in DuBeVeg by reducing the probability of erosion of the area where offshore sand was originally deposited. This effect was applied to the original surface of the nourishment and below. New sand deposits were schematized to have a higher probability of erosion, comparable to the original beach.

3. Preliminary results & outlook

The preliminary results show that the processes added to the model, combined with the previously included processes, can produce realistic predictions of the development of the SM. The Gaussian function that is implemented to represent longshore transport successfully represents the retreat of the SM in a 10-year simulation (Fig. 1). The simulated retreat of the shoreline at the center of the mega-nourishment was 360 m, while the observed retreat was 390 m. Dune shapes, dimensions and spacing simulated with the extended DuBeVeg model also agree with the dune formation observed at the SM over the past 10 years. The initial flat surface is transformed into a Nebkha-dune landscape, with simulated embryo dune lengths ranging from 2 to 10 m and heights of up to 1 m (Fig. 2). These results indicate that the extended DuBeVeg model can be used to effectively simulate the morphological development of mega-nourishments. The model can thus be used to assess the realization of the intended goals of mega-nourishments for different configurations and scenarios, e.g. permanent vs. transient nourishments, or different heights and dimensions of the initial nourishment.

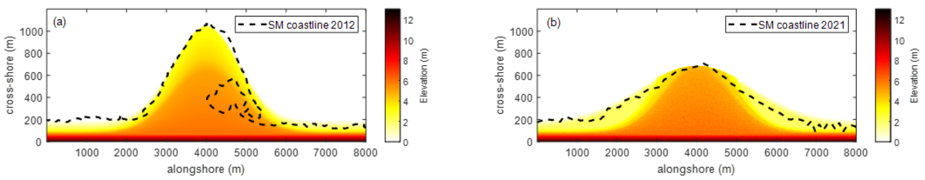

Fig 1. (a) Initial topography, (b) final topography after a 10-year simulation.

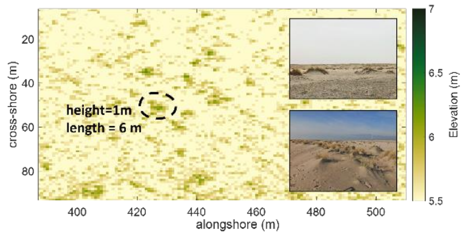

Fig 2. Model output of the simulated dune field. Photo inserts show similar dune shapes observed in the field.

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