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ABSTRACT
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Role of stochastic forcing in coastal dune vegetation

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ABSTRACT

The relevance and fragility of coastal dune systems are widely recognized. Various conceptual and numerical models have been formulated so far to cope with the threats that affect coastal systems worldwide. These models acknowledge the fundamental influence of vegetation in controlling coastal dunes stability but usually disregard some of the factors affecting coastal dynamics, such as the randomness of the driving forces. In agreement with these observations, a new model for the coastal dune vegetation is here briefly described, and one simplified version is applied to estimate the natural beach width.

1. Introduction

Sand beaches occupy approximately the 31% of the world's ice-free shoreline (Luijendijk et al. 2018) and are, therefore, one of the most common landforms over the coasts worldwide, acting as a buffer between terrestrial and marine ecosystems and providing habitats for numerous and highly specialized plant and animal species. The environmental relevance of coastal dunes is also related to the protection that they offer to human settlements and facilities from coastal hazards. Dunes shelter coastal areas from erosion and the detrimental action of salt spray. Coastal dunes are, indeed, resilient barriers that dissipate most of the energy incoming from storms through self-erosion. Moreover, they are sand reservoirs that contribute to preserving the natural equilibrium of beaches by increasing their resilience and their capability to recover after storms.

The spatial and temporal evolution of coastal dunes results from the continuous interactions between sand, vegetation and soil moistures, whose dynamics are driven by the random occurrence and magnitude of wind, sea-level fluctuations and precipitation. Vegetation is the key element in dune accretion and stabilization, and the associated increase of coastal resilience. For this reason, vegetation is the main subject of the activities that are usually planned to protect and restore coastal areas.

2. The model

Different conceptual and numerical models have been proposed so far to model coastal dune dynamics. All these models highlight the central role of pioneer vegetation in dune formation and stabilization, usually encompassing part of the stressing factors for vegetation growth that the literature identifies (Hesp 1991). However, although it is acknowledged that random forcing can highly affect dynamical systems (Ridolfi et al. 2011), the randomness that characterises wind and seawater level fluctuations is mostly disregarded in these models, which instead assume deterministic forcing.

Starting from the works of Durán and Moore (2013) and Moore et al. (2016), which consider the detrimental effect of sand movement on vegetation, a new model is here proposed. This model encompasses the randomness of the wind regime, the water level fluctuations, and the related salt spray transport. Differently from the previous approaches, the density cover of vegetation is modelled according to a dichotomic process that accounts for the aforementioned forcing in addition to the distance from the shoreline, and the intrinsic features of coastal dune plants. All these factors concur to define a threshold distance representing the range of marine disturbance. Within this, vegetation only undergoes a decay process because of anoxia and uprooting. Conversely, outside this range, vegetation dynamics is more complex, as plants can experience both growth (logistic vertical growth and lateral expansion) and wind-induced decay (induced by root excavation or tissue abrasion).

3. Application to a real case

Although this model is meant to be solved numerically, an analytic solution can be found under two simplifying hypotheses: (i) the spatial coupling is neglected and (ii) the rate of sand deposition is positive and constant, that is the rate of vegetation growth is assumed to be constant. Accordingly, the model reduces to a single stochastic differential equation whose solution is the steady-state probability density function of the vegetation cover and its statistical moments. If applied to simple geometries, as a longitudinal beach profile of constant slope, this model allows us to estimate the extension of the beach width, namely the distance from the shoreline where pioneer vegetation can establish and trigger dune formation. Notice that this distance roughly corresponds to the *coastal high hazard area* (CHHA), a definition which is commonly used in coastal management.

The calibration and validation of the model were carried out by comparing the computed beach widths with the distances measured by remote sensing for a set of randomly chosen locations. The model demonstrated to be able to estimate the threshold distance for the colonization of pioneer vegetation with good precision, as the estimation error was generally lower than 10 m, which corresponds to the spatial resolution of the used remote sensing images.

4. Conclusions

The basic features of a new model for coastal vegetation dynamics have been described, showing one of its potential application. The simplified model allowed us to accurately estimate where the pioneer plants firstly establish on a bare sand beach, also determining the position of the crest of the incipient foredune. These results can constitute useful information for the definition of coastal hazard areas and dune restoration activities. In conclusion, the model can be applied to anthropized areas where the original foredune landscape has been widely altered by human facilities, as shown in Fig.1, providing the extent of the coastal areas that should be preserved to guarantee the natural protection the dunes offer to the inland.

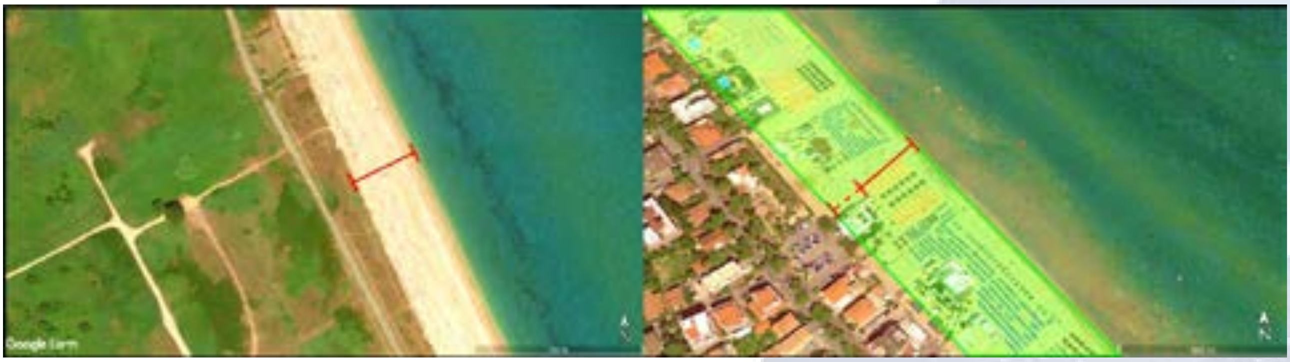

Fig. 1. Comparison between a natural coastal area in Abruzzo (Italy), and an anthropized sand beach that is located just a few km southward. The left panel shows the distance between the foredune and the shoreline (red line), whereas the right panel indicates approximately the area that should have been left natural to benefit from the protection of coastal dunes (green). The width (red line) of this area is the sum of two terms. The former (solid line) is the distance between the foredune and the shoreline and it is provided by the model. The latter (dotted line) is the foredune width, which is a function of the former distance.

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