Plant establishment and plant-sand feedbacks as fundaments for dune-for-dike nature-based solutions

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Coastal foredunes serve as a natural defense against rising sea levels and storm floods, support important Natura2000 biodiversity and habitats, and offer areas for human recreational activities. Along urbanized coasts, a large proportion of dune systems have been replaced with hard infrastructures such as dikes and sea walls. Over the past decade, the limitations of these traditional grey infrastructures (their static character and high maintenance costs) were recognized. This caused scientists across many disciplines to **explore coastal dunes as nature- based solutions** for sustainable and cost-effective long-term coastal protection.

Coastal dunes develop from ecological interactions between sand fluxes and vegetation development. Plant-sand feedbacks are the basis for the unique dynamic and self-organizing properties of coastal dunes. These properties are anticipated to make them resilient and responsive to tidal and wave conditions, and hence future climate change impacts. The construction of **hybrid dune-dike systems**, where dunes are built in front of the dike, emerges as a promising solution to secure coastal regions against floods and storms.

To allow the design, the creation but also the natural development of such dune-dike hybrid nature-based solutions in the most optimal way, we have to understand the responses of plants to changes in environmental conditions, as well as their effects on the environment.

First, to be able to predict where natural dune development is possible, I constructed an **ecological niche model for embryo dune plants** on the Belgian coast. These embryo dune plants are the pioneer plants responsible for the natural initiation of dune development on the high beach. They consist of (rare) annual species that lay the foundation for further dune development and are subject to both human and environmental stressors. I built a spatio-temporal regression model, based on annual sand dynamics and flooding potential, to deduce and demonstrate that the establishment of embryo dunes is feasible along the entire Belgian coast, but is mainly constrained by mechanical beach cleaning and beach management.
Second, to be able to **optimize the construction of dune-for-dikes** through planting strategies of marram grass, I analyzed how the abundance and spatial configuration of marram grass impact the development of established pilot dune-dike hybrids along the Belgian coast. This mechanistic insight on sand burial-plant growth interactions allows for a better prediction of the outcome of different marram grass planting strategies, and the corresponding dune shape and characteristics related to storms and erosion.
In conclusion, my research emphasizes the importance of understanding the ecological dynamics of coastal dunes as essential components to gain a dynamic rather than static understanding of dune-dike hybrid nature-based solutions for effective coastal and biodiversity protection.

Keywords
Spatio-temporal Modeling; Plant Ecology; Dune Engineering; Nature-based Solutions; Climate Change