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A bio-geomorphic model for smart design of climate resilient tidal marsh restoration

Stijn Temmerman (1), Jim Van Belzen (1,2), Olivier Gourgue (1), Christian Schwarz (3), Tjeerd J. Bouma (2), and Johan Van de Koppel (2)

(1) Ecosystem Management Research Group, University of Antwerp, Antwerp, Belgium, (2) Department of Estuarine and Delta Systems, NIOZ Royal Netherlands Institute for Sea Research and Utrecht University, Yerseke, the Netherlands, (3) Coastal Research Group, Department of Physical Geography, Utrecht University, Utrecht, the Netherlands

Tidal marshes provide highly valued ecosystem services, including nature-based coastal protection, carbon sequestration, and sustaining biodiversity. In many places, however, tidal marshes are vulnerable to degradation by sea level rise, and direct human land occupation has resulted in large-scale loss of tidal marsh ecosystems. Consequently, restoration of formerly degraded or lost tidal marsh landscapes is nowadays starting to be implemented at ever larger scales in many estuaries and deltas around the world. Furthermore these restored coastal wetlands need to be resilient to future global and local changes such as accelerating sea level rise.

Important questions are how successful and how fast a resilient tidal marsh can be restored, depending on initial landscape conditions, and whether the rate and success of marsh restoration can be steered by pre-designing the initial landscape. In order to answer such questions, we developed a new numerical model allowing the simulation of bio-geomorphic landscape development from bare tidal flats to vegetated marshes, through dynamic feedbacks between vegetation dynamics (colonization, expansion, die-back), hydrodynamics (tides) and morphodynamics (erosion, sedimentation, channel formation). Complementary to previous models for marsh eco-morphodynamics, our new model is able to run on large, complex, real topographic domains of several km^2, accounting for vegetation dynamics at sub-meter resolution, and simulating several decades of landscape evolution in response to different input boundary conditions such as sea level rise scenarios.

Here we present results for a real-life large-scale ($\sim$5 km^2) coastal managed realignment project in the Scheldt estuary (Netherlands & Belgium), where a former agricultural polder area protected from flooding by dikes will be redeveloped into a tidal flat and marsh ecosystem by controlled breaching of the dikes and subsequent re-introduction of tides. The predicted rates of vegetation colonization, marsh platform sedimentation and channel formation are compared to observed data from nearby existing marsh environments. We present model scenarios showing the importance to account for the typically patchy and stochastic establishment of pioneer vegetation in order to predict realistic rates of vegetation development and its effects on the morphodynamic landscape evolution. Further scenarios demonstrate that the rates of vegetation development and of sedimentation can be steered by pre-designing the initial landscape conditions. The ability to steer the landscape development is highly relevant, for instance, as sedimentation rates determine the capacity of coastal marshes to keep up with future scenarios of sea level rise or not. Specifically, we show that smart design of the dimensions of the controlled dike breaches can be used to steer tidal flood and ebb velocities, thereby enhancing or tempering the rates of sedimentation and plant colonization, in balance with sea level rise scenarios. Hence the presented bio-geomorphological model approach provides a useful tool for smart design of large-scale marsh restoration projects and to facilitate the development of resilient marsh ecosystems.