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Biomorphological modeling of tidal landscapes: the role of physical and biological processes in determining equilibrium states and transient dynamics

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Changes in relative sea level, nutrient and sediment loading, and ecological characteristics expose tidal landforms and ecosystems to responses which may lead to abrupt switches among different equilibrium states. The prediction of such responses is important in view of the ecological, cultural and socio-economic importance of these sensitive tidal environments.

We describe a point model of the joint evolution of tidal landforms and biota which incorporates the dynamics of intertidal vegetation, benthic microbial assemblages, erosional, depositional, and sediment exchange processes, and wind-wave dynamics. We then apply it to the Venice lagoon, to explore the equilibrium states and the transient behaviour of tidal bio-geomorphic systems under varying physical and biological forcings. Alternative stable states and punctuated equilibria emerge, characterized by possible sudden transitions of the system state: they are governed by vegetation type, disturbances of the benthic biofilm, sediment availability and marine transgressions or regressions.

The explicit and dynamically-coupled description of biotic and abiotic processes emerges as a key requirement for realistic and predictive models of the evolution of a tidal system as a whole. The analysis of such coupled processes indicates that hysteretic switches arise between stable states because of differences in the threshold values of relative sea level rise inducing transitions from vegetated to unvegetated equilibria and viceversa, with implications for the preservation of tidal environments under a climate change.

We explore the transient behaviour of the system forced by synthetic and observed rates of sea-level rise. Numerical experiments with different observed forcings in the Venice Lagoon suggest that the existence and characteristics of equilibrium states depend quite strongly on the local tidal regime. This occurs even within the same tidal system, because of the different meteorological contributions which significantly alter the characters of the local tide. Moreover numerical experiments carried out with different synthetic tides show that the high tidal levels produce an important stabilizing effect by reducing the erosion rate on the subtidal platform. Tidal amplitude thus decreases the intensity of erosion processes over the subtidal platform and marsh equilibrium elevations decrease as the tidal amplitude increases.

In addition we observe that the local wind produces a very important effect on the subtidal equilibrium state. Subtidal equilibria resulting from wind observations at sites separated by a few kilometers show important elevation differences on the stable equilibrium.

Finally we identify the effects of the characteristic response time of vegetation to environmental changes on the overall system dynamics observing that the time in which the vegetation reaches the equilibrium is relatively brief, suggesting that biomass adjustments to elevation changes may indeed often assumed to be almost instantaneous.