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Bio-geomorphic feedback causes alternative stable landscape states: insights from coastal marshes and tidal flats

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Many bio-geomorphic systems, such as hill slopes, river floodplains, tidal floodplains and dune areas, seem to be vulnerable to shifts between alternative bare and vegetated landscape states, and these shifts seem to be driven by bio-geomorphic feedbacks. Here we search for empirical evidence for alternative stable state behavior in intertidal flats and marshes, where bio-geomorphic interactions are known to be intense.

Large-scale transitions have been reported worldwide between high-elevation vegetated marshes and low-elevation bare flats in intertidal zones of deltas, estuaries, and coastal embayments. It is of significant importance to understand and predict such transitions, because vegetated marshes provide significant services to coastal societies. Previous modeling studies suggest that the ecological theory of catastrophic shifts between alternative stable ecosystem states potentially explains the transition between bare flats and vegetated marshes. However, up to now only few empirical evidence exists. In our study, the hypothesis is empirically tested that vegetated marshes and bare tidal flats can be considered as alternative stable landscape states with rapid shifts between them. We studied historical records (1930s – 2000s) of intertidal elevation surveys and aerial pictures from the Westerschelde estuary (SW Netherlands). Our results demonstrated the existence of: (1) bimodality in the intertidal elevation distribution, i.e., the presence of two peaks in the elevation frequency distribution corresponding to a completely bare state and a densely vegetated state; (2) the relatively rapid transition in elevation when intertidal flats evolve from bare to vegetated states, with sedimentation rates that are 2 to 8 times faster than during the stable states; (3) a threshold elevation above which the shift from bare to vegetated state has a high chance to occur. Our observations demonstrate the abrupt non-linear shift between low-elevation bare flats and high-lying vegetated marshes, suggesting that bare and vegetated states are potentially alternative stable landscape states with the occurrence of relatively abrupt shifts between them.