Does alternative stable states theory and catastrophic shift theory apply for bare intertidal flats and vegetated marshes?

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The vegetation of intertidal marshes provides important ecosystem services to coastal societies, such as the reduction of wave-induced coastal erosion and attenuation of landward flood propagation during storm surges. These positive effects of intertidal marsh vegetation may change in time, because intertidal areas may shift from bare mudflats to vegetated marshes or vice versa. It is therefore important to allow the understanding and prediction of pending shifts between bare and vegetated states of intertidal areas. The concept of catastrophic shifts between bare mudflats and vegetated marshes has been explored only recently by numerical modeling and up to now only few empirical evidence has been presented in the literature. In our study, we tested the hypothesis that bare tidal flats and vegetated marshes can be considered as alternative stable landscape states with the occurrence of rapid catastrophic shifts between the two stable states. We studied this by analyzing a detailed historical record of intertidal elevation surveys and aerial pictures from the Westerschelde estuary (SW Netherlands). We examined the bimodal distribution of elevations in the intertidal areas. We tested the rapid elevation shifts from bare flats to vegetated marshes. Finally, we studied whether we can predict such shifts based on the intertidal elevation. Our results indicated that vegetated intertidal marshes lie within a small range of high elevations, while bare intertidal flats dominate a different range of lower elevations. The intermediate elevations are less frequent. Analysis of the areas that shifted from bare flats to vegetated marshes revealed that the shifts occur relatively rapid and that the shifts always seem to have occurred once the peak of the elevation distribution had exceeded a threshold value around -0.6m. Study of pioneer patches in 2004 showed that most of pioneer patches occurred in the elevation range of -0.8 m to -0.4 m, which includes the aforementioned threshold elevation where the system shifts from bare to vegetated states. Probability maps were constructed as a prediction for the shift from bare to vegetated state. The success of prediction is highly different for the onshore and offshore flats. A high probability on the onshore flats mostly results in a shift to vegetation by the next time step, while not necessarily on the offshore flats. In conclusion, our results indicate empirical evidence for the application of alternative stable states theory and catastrophic shift theory in intertidal ecosystems.