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Regime shifts in river deltas

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River deltas harbor invaluable ecosystems as well as many of the world's largest cities and are hotspots for economic activity. This necessitates accurate prediction of the response of delta biogeomorphology to future scenarios of changes in sea level, wave climate, river discharge dynamics and anthropogenic forcing. Valuable insights have come from long-term model predictions performed with high-complexity simulation models. Such models often predict a gradual adjustment of biogeomorphic equilibrium to changing forcing conditions. On the other hand, a growing number of studies, based on strongly idealized models, indicate the presence of tipping points where delta systems may undergo irreversible regime shifts to an alternative stable state. Examples include estuarine (hyper)turbidity, delta channel instability and ecosystem emergence or collapse. However, field observations to support either the predicted absence or presence of irreversible regime shifts in river deltas remain scarce.

Our study reviews the existing research on reversible (single equilibrium) and irreversible (multiple equilibria) transitions in delta biogeomorphology. We propose how to bridge the apparent gap between high-complexity models, which accurately capture reversible morphodynamic adjustment to small changes in forcing but are unpractical to probe wide parameter ranges for the presence of irreversible regime shifts, and idealized models, which have contrasting characteristics. We discuss (the lack of) existing field data to support morphodynamic model predictions and specify which field measurements would be needed to provide more conclusive evidence. Specific attention is given to early warning indicators for regime shifts, such as spatial patterning and critical slowing down, and which of these signals could be picked up in delta systems. Finally, we illustrate how the design of human interventions, such as channel dredging, beach nourishments and ecosystem restoration, requires fundamental knowledge of a delta's natural resilience, as lower resilience implies higher susceptibility to irreversible regime shifts.