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Catastrophic shifts in vegetation-soil systems may unfold rapidly or slowly independent of the rate of change in the system driver

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Complex systems may switch between contrasting stable states under gradual change of a driver. Such critical transitions often result in considerable long-term damage because strong hysteresis impedes reversion, and the transition becomes catastrophic. Critical transitions largely reduce our capability of forecasting future system states because it is hard to predict the timing of their occurrence [2]. Moreover, for many systems it is unknown how rapidly the critical transition unfolds when the tipping point has been reached. The rate of change during collapse, however, is important information because it determines the time available to take action to reverse a shift [1]. In this study we explore the rate of change during the degradation of a vegetation-soil system on a hillslope from a state with considerable vegetation cover and large soil depths, to a state with sparse vegetation and a bare rock or negligible soil depths. Using a distributed, stochastic model coupling hydrology, vegetation, weathering and water erosion, we derive two differential equations describing the vegetation and the soil system, and their interaction. Two stable states – vegetated and bare – are identified by means of analytical investigation, and it is shown that the change between these two states is a critical transition as indicated by hysteresis. Surprisingly, when the tipping point is reached under a very slow increase of grazing pressure, the transition between the vegetated and the bare state can either unfold rapidly, over a few years, or gradually, occurring over decennia up to millennia. These differences in the rate of change during the transient state are explained by differences in bedrock weathering rates. This finding emphasizes the considerable uncertainty associated with forecasting catastrophic shifts in ecosystems, which is due to both difficulties in forecasting the timing of the tipping point and the rate of change when the transition unfolds.

References

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