Empirical analysis of vegetation dynamics and the possibility of a catastrophic desertification transition

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Systems governed by nonlinear dynamics may support alternative steady states. When such a system is driven by external force it may change its state abruptly at the tipping point, where one of the equilibrium states loses its stability. In ecological systems these shifts are often harmful, causing a loss of bioproductivity and biodiversity, which, in turn, may negatively affect ecosystem functions and stability. Therefore, the possibility that ecosystems may undergo such an irreversible transition in response to small and slow environmental variations raises a lot of concern. In particular, the process of desertification in the semi-arid climatic zone is considered by many as a catastrophic regime shift, since the positive feedback of vegetation density on growth rates yields a system that supports alternative steady states.

However, in spatial systems positive feedback and alternative steady states of the local dynamics are not sufficient conditions for a catastrophic transition. Even in the presence of these factors, the transition from one stable state to another may be gradual. Two main scenarios of gradual transitions were pointed out in the literature. First, the effect of stochasticity may lead to a continuous transition, depending on its strength and on system's spatial features [1,2], second, local disturbances may generate a moving front between the two states [3].

We present, for the first time, a large-scale analysis of vegetation dynamics 2.5 million squared kilometers of the African Sahel region, with spatial resolution of 30X30 meters, using three consecutive snapshots. The density dependence of the local growth rate is shown to be purely negative, while the spatial response of vegetation patches indicates a positive feedback at small-intermediate geographic scales. These apparently contradicting results emerge naturally in a model with positive feedback and strong noise, a model that allows for a catastrophic shift only in a certain range of parameters [2,4]. Our results cast serious doubt on the assumption that the desertification transition is a catastrophic shift, and call for an interpretation of the results using models that stress spatial structure and the effects of stochasticity. Static patterns, like the double peak in the histogram of vegetation density, are shown to vary between censuses, with no apparent correlation with the actual dynamical features.

[l] Weissmann and Shnerb, EPL **106**, 28004 (2014).

[2] Martin et al, PNAS **112**, E1828 (2015).

[3] Bel et al, Theor. Ecol. **5**, 591 (2012).

[4] Weissmann and Shnerb, JTB **397**, 128 (2016).