Self-organized patchiness and catastrophic shifts in real and model ecosystems

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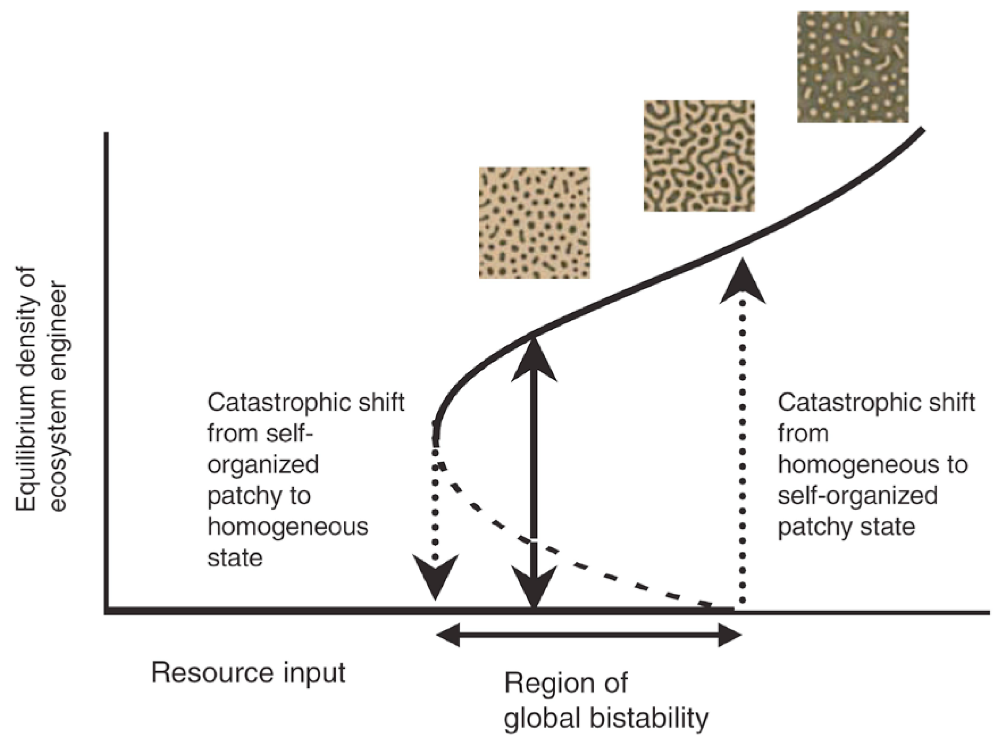
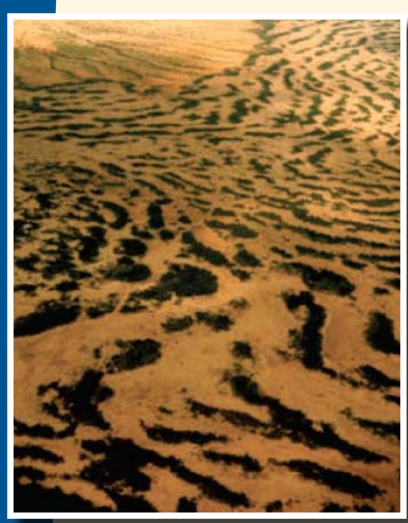
Introduction

Gradual changes in the environment may induce unexpected sudden catastrophic shifts in ecosystems, with concomitant losses or gains of ecological and economic resources. Such shifts have been observed in the past, and concern has risen that such shifts may occur in the future because of global climate change. However, verifications and predictive power with respect to catastrophic ecosystem responses to a changing environment are currently lacking. The aim of this VIDI project is to examine whether self-organized patchiness indicates proximity to catastrophic shifts.

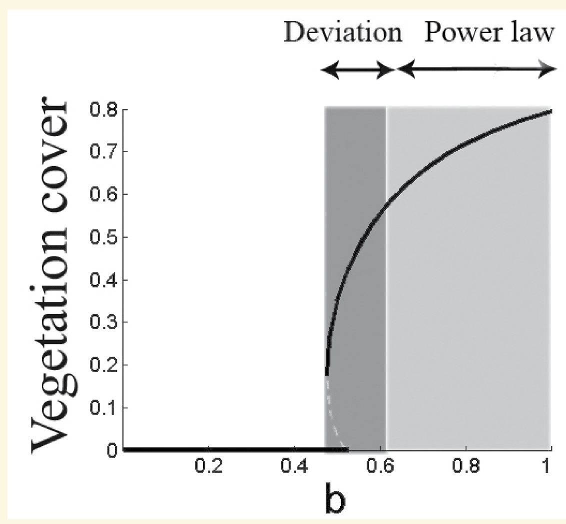
Methods & Hypothesis[1]

Two types of ecosystem shifts are studied:
1) desertification of arid ecosystems and
2) rapid vegetation (and hence carbon sequestration) change in peatlands. First, we developed mathematical models, which uncovered possible feedback mechanisms inducing self-organized patchiness in these systems, and showed that these feedbacks could trigger catastrophic shifts. Subsequently, we tested model predictions with empirical data.



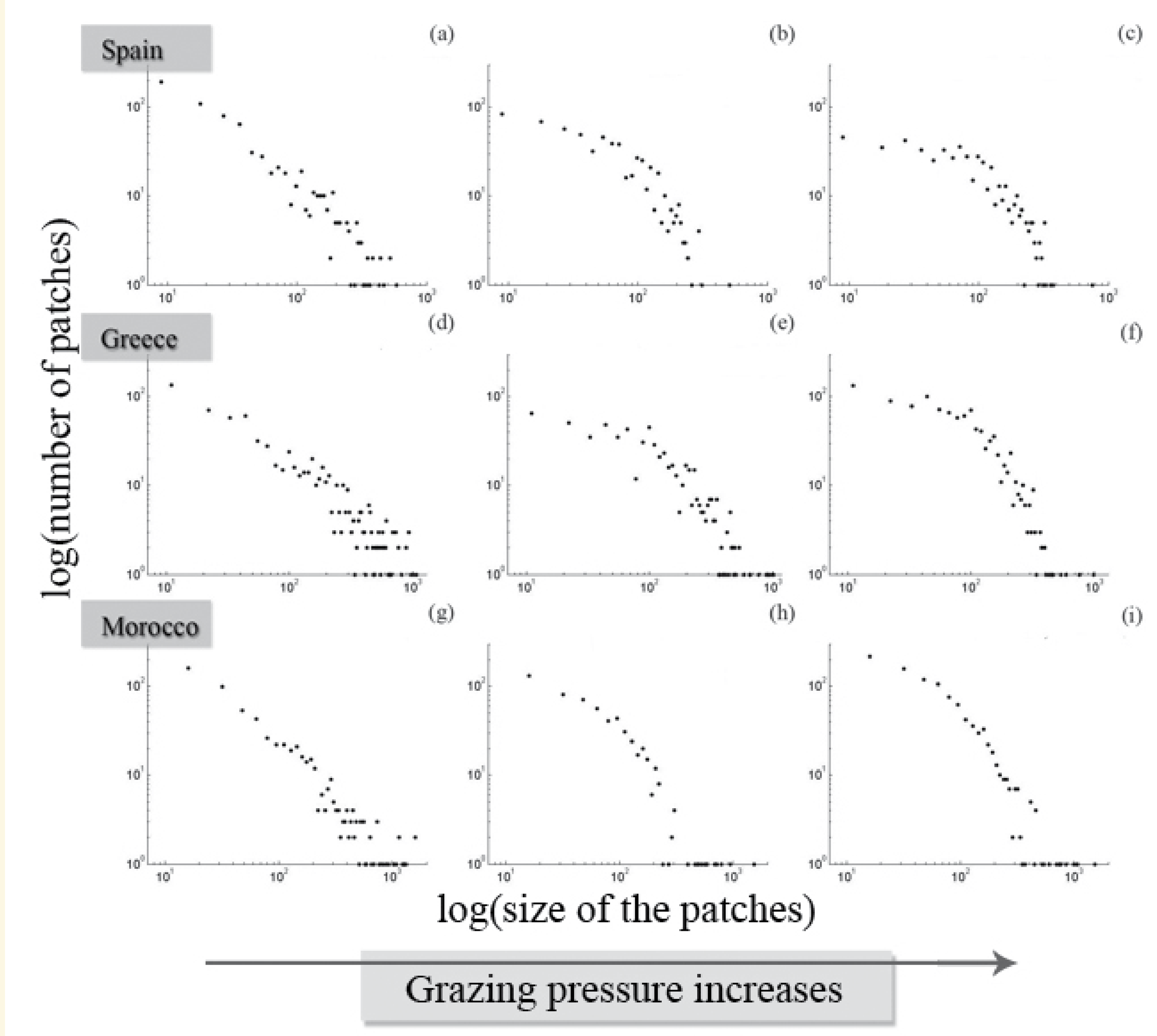


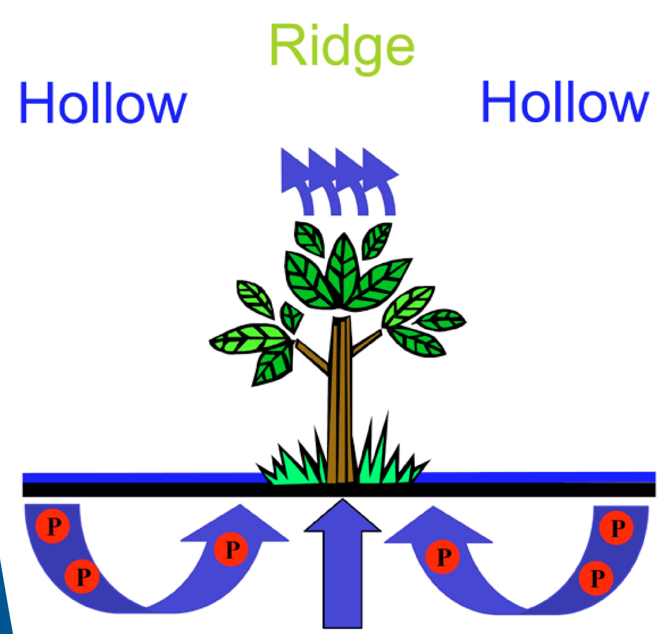
Model result: Close to the transition to desert due to overgrazing or, in this case, aridity (b), patch size distribution starts deviating from a power law.

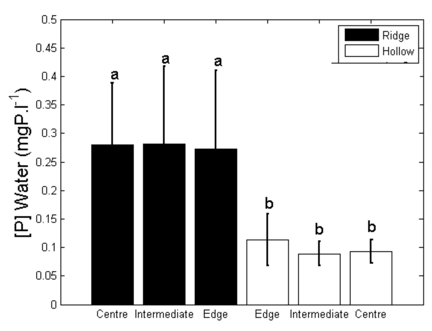


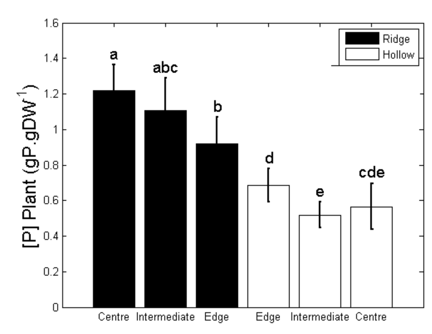
Arid ecosystems[2]

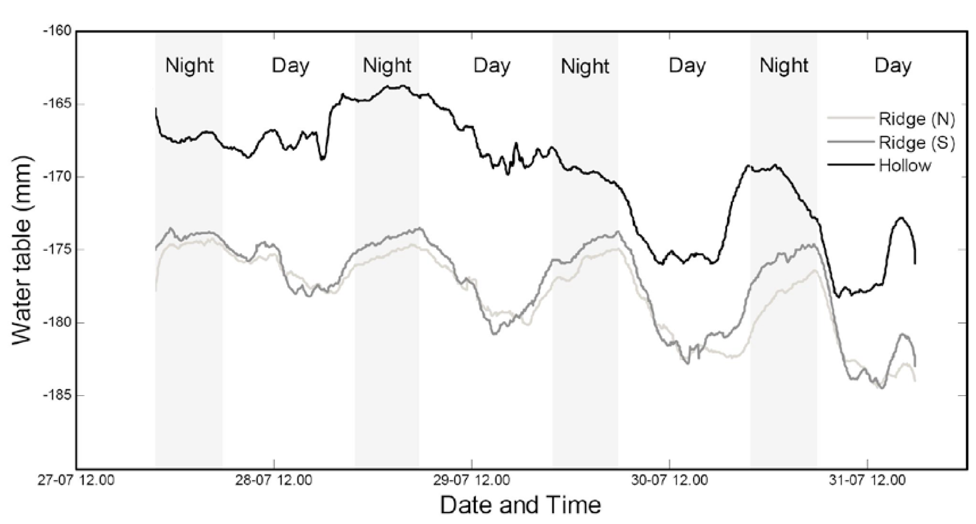
Climate change and overgrazing are the two main factors responsible for desertification of drylands. In extensively grazed ecosystems in Spain, Greece and Morocco, patch size distribution of the vegetation followed a power law, but with increasing grazing pressure, field data revealed consistent deviations from these power laws. Together with model simulations, these results show that patch size distribution can serve as an early warning signal for imminent desertification of arid ecosystems.











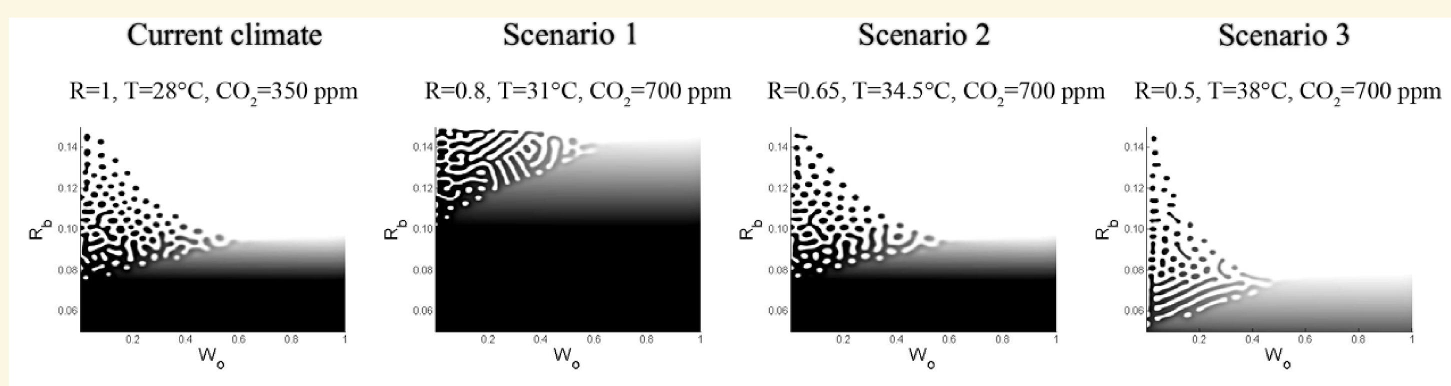
Peatland ecosystems[3,4]

Paleoecological studies reported rapid shifts in vegetation and hence carbon sequestration in peatlands in the past. Simulation models suggest that these shifts could be explained by a feedback between increased transpiration by vascular plant growth and nutrient availability. Field data from a self-organized Siberian peatland (consisting of densely vegetated ridges and sparsely vegetated hollows) confirm that transpiration is a key factor inducing a net water and nutrient flow towards ridges.

Conclusions & Perspectives[5]

We conclude that for both systems, feedback control may induce self-organized patchiness, which indicates the possibility of catastrophic shifts if environmental conditions change. The developed models can now be used for extrapolation over several spatial and temporal scales, that is to predict the response of arid and peatland ecosystems to global change using future climate scenarios (elevated CO_2, changes in temperature and precipitation).

References: [1]Rietkerk et al., Science, 2004 • [2]Kéfi et al., submitted for publication • [3]Eppinga et al., Plant Ecology, 2007 • [4]Eppinga et al., submitted for publication • [5]Kéfi et al., submitted for publication



Model predictions of the response of arid ecosystems to climatic changes in rainfall (R), Temperature (T), and atmospheric carbon dioxide concentration (CO2). The response of arid ecosystems to such changes in climate depends on site-specific soil characteristics (W_0; low values correspond to clayey soils, higher values to sandy soils) and plant physiological properties (R_B; the per capita plant respiration rate). Especially systems with high respiring plants on clayey soils become vulnerable under the most pessimistic scenario.

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