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Modelling ecogeomorphic feedbacks: investigating mechanisms of land degradation in semi-arid grassland and shrubland

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Across vast areas of the world's drylands, land degradation is exacerbated by ecohydrological processes, which alter the structure, function and connectivity of dryland hillslopes. These processes are often interlinked through feedback mechanisms in such a way that a trigger may result in a re-organization of the affected landscape. Here, we present a spatially explicit process-based ecogeomorphic model, MAHLERAN-EcoHyD to enhance our understanding of complex linkages between abiotic and biotic drivers and processes of degradation in drylands. This ecogeomorphic modelling approach is innovative in two main ways: it couples biotic and abiotic processes, and simulates intra and inter-event dynamics, thus overcoming a key limitation of previous modelling approaches in terms of their temporal scaling, by simulating key ecogeomorphic processes at process-relevant time steps. Redistribution of water, sediment and nutrients during high-intensity rainstorms is simulated at 1-sec time steps, soil moisture and transpiration dynamics at daily time steps, and vegetation dynamics (establishment, growth, mortality) at 14-day time steps, over a high-resolution 1x1 m grid.

We use this innovative modelling approach to investigate soil-vegetation feedback mechanisms within a grassland-shrubland transition zone at the Sevilleta Long Term Ecological Research site in the south-western United States. Results from three modelling experiments are presented: the first modelling experiment investigates the impact of annual variations in individual high-intensity storms to assess long-term variations in runoff, soil-moisture conditions and sediment and nutrient fluxes over two decades; the second modelling experiment assesses the impact of vegetation composition on spatial changes in surface soil texture due to soil erosion by water; and the third modelling experiment investigates how long-term changes in vegetation alter feedbacks between biotic and abiotic processes using scenarios for static vegetation, dynamic vegetation and two stress scenarios (drought and overgrazing).

Results of the first modelling experiment show that total runoff and sediment fluxes are reproduced reasonably well for larger storm events, yet fluxes are generally underestimated for smaller storm events due to the greater sensitivity of simulated runoff to discrepancies in simulated surface soil-moisture content. Results from the second modelling experiment reveal that although the spatial average of fine sediment fractions does not change, the spatial distribution of fine sediment fractions does change, especially over the shrub-dominated plot. This difference is particularly significant since the fine sediment fraction has the highest concentration of plant-essential nutrients. Results from the third modelling experiment show that if grass cover is low (~20%), then sensitivity to stress scenarios is high, whereas if grass cover is high (~40%), then grass and shrubs may co-exist under stress conditions. Results also show that in dry years when soil-moisture content remains high in the lower soil layer, the system is more resilient to meteorological drought.

This ecogeomorphic model thus closes the gap of current modelling approaches that either investigate only individual extreme events or model the long-term dynamics of a landscape without including feedbacks between abiotic and biotic processes. This ecogeomorphic model therefore allows novel insight into the interactions and feedbacks between biotic and abiotic processes that govern ecosystem state in drylands.