Testing Non-Equilibrium Theory: Effects of Grazing on Plant Community Composition and Soil Nutrient Availability in Dry Southern Mongolian Steppes

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Introduction Large parts of the Central Asian rangelands are dry at mean precipitation levels of < 200 mm , and show a pronounced interannual variability in climate (CV > 30%) . The *non equilibrium-*(or *disequilibrium-* , Gillson & Hoffman , 2007) *theory* of rangeland science predicts for such environments that climate is the main control with biotic factors including grazers' impact being driven by , rather than driving variables . In this view , degradation threat should be small in dry regions . We tested these assumptions by monitoring vegetation composition in grazed and ungrazed sites in southern Mongolian desert steppes over 8 subsequent years . Our focus was on the relative importance of interannual climate variability vs . grazing impact/ exclusion . Ongoing discussions on the possibility of degradation occurring even under *non-equilibrium* conditions prompted us to assess whether grazing alters soil conditions and if possible changes indirectly affect rangeland health .

Materials and methods Studies were conducted in southern Mongolian desert steppes that receive well below 200 mm annual precipitation (mainly summer) . We used permanent grazing exclosures and adjacent controls to monitor vegetation development . Transect studies radiating away from traditional high impact sites were employed to assess long-term effects of gradients in livestock activity . We also determined the impact of burrowing small mammals (Mongolian Pika , *Ochotona pallasi*) on vegetation and site conditions . Results pointed to effects of nutrient limitation so we also conducted an NPK fertilization experiment and added fertilizer at equivalents of 10 and 20 gN/m (100 & 200 kgN/ha) .

Results Exclosure studies demonstrated a pronounced interannual variability in plant community composition and productivity , which were related to the variability in precipitation . Grazing also had significant effects on community structure , but these were small compared to the rain effect . Studies along transects of 2 km length also showed no effects of grazer activity on plant community compositions along the land use gradients (Stumpp et al . , 2005) . They gave , however , evidence for nutrient translocation as small livestock (mainly goats and camels) release nutrients particularly phosphate—at some few high impact points . Exclosure studies also indicated soil and nutrient accumulation in fences .

Small mammals consumed a fraction of aboveground biomass comparable to the uptake by livestock , and pikas also translocated nutrients . They operate on scales of few metres and concentrate N and P on their burrows thereby counteracting large-scale nutrient dislocation by livestock . Vegetation on burrows differed in composition and was more productive than the surrounding steppe (Wesche et al . , 2007) .

After fertilization , uptake of nutrients was increased though far from complete and nutrients accumulated in the soil . Plant biomass and flower production varied strongly with annual precipitation levels (annual totals 2004-189 mm , 2005—113 mm , 2006—ca . 150 mm) , but fertilization always led to a two-to threefold increase in productivity and reproduction .

Conclusions Our results confirmed the importance of abiotic controls on plant community composition and performance implied by the *non-equilibrium theory* . Auxiliary data showed that populations of livestock and small mammals indeed showed pronounced interannual fluctuations , and evidence for strong direct effects of grazing on vegetation is indeed limited . However , livestock withdraws nutrients from the rangelands and the fertilization experiment showed that rangeland performance is at least co-limited by nutrients even in dry years . These results point to an indirect pathway of pasture degradation that has hardly been assessed in Central Asia . Data also support the notion that focusing on precipitation alone is an oversimplification even in dry rangelands , and thus the *non-equilibrium theory* needs improvement .

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