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## Social-ecological tipping points in the rangeland system in the Waterberg region in Namibia

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### Abstract

The literature on ecological tipping points (TP) is well established and publications on social TPs are increasing, while empirical studies focussing on the interlinked social-ecological perspectives of TPs are scarce. We studied social-ecological TPs in a rangeland system subjected to climate change to identify state changes with limited reversibility towards degradation in several cascades triggered by positive feedback loops running through the ecological and the social subsystem. For this, we analysed qualitative and quantitative data from extensive research on rangeland management in the Waterberg area in Namibia. One state change in the ecological subsystem is a cascading process going from a rangeland with abundant perennial and annual grasses to a rangeland dominated by annual grasses, to the occurrence of invasive species, and bare soil. Bush encroachment is the second detected ecological state change. The state change in the social subsystem is connected to the carrying capacity of the rangeland, farm income, and farm organisation. We identified several positive (self-reinforcing) feedback loops in the social-ecological system (e.g. drought – loss of grass biomass – reduction of carrying capacity – overstocking if there is no destocking because of drought – overgrazing – further loss of grass biomass – use of supplementary fodder to not destock – further overgrazing until the vegetation cover is depleted) resulting in system instability and driving the whole social-ecological system towards a TP. Furthermore, we identified farmers' coping strategies such as wildlife management and tourism as well as bush thinning and use, which lead to a negative feedback loop and enhance social-ecological system stability. Wildlife is better adapted to the ecosystems and bush thinning restores the rangeland temporarily. Both increase farm income and stabilise the social subsystem. In contrast, off-farm income stabilises the social subsystem, but leads to overstocking contributing to positive feedback loops in the social-ecological system. While the loss of vegetation cover and seedbank depletion are hardly reversible, bush encroachment can be reversed temporarily through bush thinning. There are signs of a negative social-ecological TP, but also of a state change to a more resilient social-ecological system.

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