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How much climate change can pastoral livelihoods tolerate? Modelling rangeland use and evaluating risk

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ABSTRACT

Livestock is the most important source of income for pastoral livelihoods in drylands. Pastoralists have developed flexible resource utilization strategies that enable them to cope with the high spatio-temporal resource variability typical to these areas. However, climate change in the form of decreasing mean annual precipitation accompanied by increasing variability has important consequences for rangeland productivity and thus pastoral livelihood security. Here, we use a spatial simulation model to assess impacts of changing precipitation regimes, and to identify limits of tolerance for these changes beyond which pastoral livelihoods cannot be secured. We also examine strategies to control these limits.

Our results indicate that: (i) while reduced mean annual precipitation always had negative effects, increased precipitation variability can have negative, none or even positive effects, depending on the vegetation's recovery potential. (ii) Depending on income requirements there are limits of tolerance to decreases in mean annual precipitation beyond which precipitation regimes overcharge the coping capacity of the pastoral household and threaten its livelihood. (iii) There are certain strategies, in particular "Increasing mobility" and "Diversifying income for coping with income risks from pastoralism", that allow the limits of tolerance to be shifted to a certain extent. We conclude that it is important to consider climate change and human requirements together to create appropriate climate change mitigation strategies in pastoral systems. Our results also shed new light on the discussion on disequilibrium rangeland systems by identifying mechanisms that can support fluctuating but non-degrading herbivore-vegetation dynamics. The paper finishes with remarks on the broader potential of the presented modelling approach beyond rangelands.

1. Introduction

In drylands, which cover more than 40% of the surface of the earth (Neely et al., 2009), livestock is the most important source of income (Walker and Janssen, 2002). Facing scarce and variable rainfall, adaptive strategies such as mobility are required to buffer highly variable natural resources and to secure pastoralists' livelihoods (Niamir-Fuller and Turner, 1999; McAllister et al., 2009). Transhumance, the traditional use of rangelands comprising steep environmental gradients with regular herd and household movements (Reid et al., 2008), is a good practice example for locally adapted and sustainable livelihood strategies. However, externally driven changes in the environment and the socio-economy may severely affect ecosystem services such as forage supply (Verstraete et al., 2009). Particularly climatic factors, like mean annual precipitation and precipitation variability, have a huge impact on rangeland condition and fodder production (Williams and Albertson, 2006). Substantial climate change is expected in the form of decreasing mean annual precipitation accompanied by increasing precipitation variability, which is recognized as an important driver for degradation of dryland productivity. However, the direction of precipitation change is discording due to uncertainties in climate models (IPCC, 2007). In several regions in north-west Africa, mean annual precipitation is projected to decrease by 10–20% (Paeth et al., 2009). Therefore, climate change is expected to threaten pastoralist livelihoods. Under which local circumstances changing rainfall characteristics may limit the ability of pastoralists to secure their livelihood sustainably if they only rely on local forage resources is an open question.

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In the past, research on the effects of changes in climate and land use focused mainly on the ecological subsystem, such as the supply of forage resources and their degradation. During the last two decades, changes in the human subsystem have become more important. The main aim of these studies was to identify causal factors of sustainable pastoralism (Niamir-Fuller and Turner, 1999; Oba, 2011). In this context, political and socio-economic constraints have been identified as major factors in the marginalization of pastoralists (Oxfam, 2008). Studies from economical perspectives elaborated strategies of risk management on stochastic pastoral income (Lybbert et al., 2004) and incentives for reciprocal agistment networks (McAllister et al., 2006; Dixit et al., 2012). Furthermore, decreasing mobility options, as a consequence of multiple drivers leading to fragmentation (Hobbs et al., 2008; Galvin, 2009), may greatly affect pastoral livelihood systems and therefore human well-being (Verstraete et al., 2009). However, it is still difficult to evaluate the relative importance and feedbacks between these external drivers. Now, it is crucial to analyze the vulnerability of pastoral livelihoods to combined threats within a risk-prone environment (Reed et al., 2008; Fraser et al., 2011) and to determine to what extent adaptive strategies can compensate for critical changes.

In this paper, we aim to identify changes in rainfall regimes that can be coped with by pastoral households, and changes which pose a threat to pastoral livelihood security. We focus on dryland systems with a high proportion of woody forage plants, such as sagebrush steppes and Mediterranean ecoystems dominated by shrubs and/or dwarf shrubs. These ecosystems are often found in rangelands comprising steep altitudinal gradients (e.g. in Northern Africa, in the Himalaya) and are typically used via transhumant pastoralism. We hypothesize that decreasing mean annual precipitation accompanied by increasing variability leads to smaller herd sizes and therewith increased risks for pastoral livelihoods. Having identified limits of tolerable precipitation regimes, we examine how robust limits are to changes in income needs, the type of vegetation and mobility.

The productivity of arid rangeland ecosystems and consequent stochastic livestock population dynamics are the subject of a controversial debate (Vetter, 2005). It was assumed that conditions of high environmental variability limit the strength of interaction between livestock and their forage resource (Ellis et al., 1993), which was used to explain limited plant response to grazing (Fernandez-Gimenez and Allen-Diaz, 1999). One implication was that these dis- or non-equilibrium systems are non-degradable, which was supported by a recent global study in homogeneous landscapes (von Wehrden et al., 2012). They presented evidence that degradation by grazing only takes place in areas with relatively stable annual precipitation. However, Illius and O'Connor (1999) stressed that spatial heterogeneity enables equilibrial forces in parts of the system regulating the feedback between livestock and so called key resource areas. According to this amendment to disequilibrium theory, even drylands with a highly variable precipitation may be degraded, if a certain portion of the rangeland (the key resource area) exists. Finally, the usefulness of the non-equilibrium theory for explaining degradation in drylands remains unclear (Gillson and Hoffman, 2007) and therewith for determining the implications for suitable management strategies.

Simulation models provide an opportunity to test basic principles of sustainable management under different socio-economic settings (Müller et al., 2007b). Specifically, abstract models are suitable for supporting system understanding by generating testable hypotheses rather than making predictions (Epstein, 2008). Many ecologic-economic models were developed to investigate semi-arid rangelands with a focus on economic evaluations (Janssen et al., 2000; Milner-Gulland et al., 2006; Higgins et al., 2007; Quaas et al., 2007; McAllister et al., 2009; Freier et al., 2011). However, only few models assess the effects of changing climatic conditions on pastures and livestock dynamics (for an exception see Köchy et al., 2008) and aim at a generic understanding of rangeland systems (see critical review in Tietjen and Jeltsch, 2007). Moreover, only few studies consider intraseasonal variability (but see Gross et al., 2006; Jakoby, 2011), as most of the ecological-economic models run on an annual timescale.

We developed a stylized model that aims to fill this gap. It simulates perennial vegetation and compares livestock dynamics under different rainfall regimes, vegetation conditions, and mobility strategies with a quarter-annual, half-annual or no movement frequency. For calibration, vegetation data and empirical patterns of pastoral mobility were used from a case study in mountainous Southern Morocco. In our analysis, we focus on increasing precipitation variability and decreasing mean annual precipitation because these are main components of projected climate change in arid rangelands besides temperature and CO_2 increases (Williams and Albertson, 2006; Scheiter and Higgins, 2009; Linstädter et al., 2010). In order to evaluate changes in terms of sustained pastoral livelihoods, we operationalized livelihood security for a household-based risk assessment. It can be interpreted as the household's specific risk attitude applying a strategy which ensures a certain level of income needs over time while tolerating a certain income variability. By analyzing livestock dynamics with respect to this risk attitude, we assess the household's vulnerability to climate change.

In the following, we present the model and explain how we operationalized livelihood security for the evaluation. The simulation results make it possible to differentiate between safe and unsafe precipitation regimes in order to estimate subsequent livelihood risk due to climate and land use change. Specifically, the role of sufficient pasture resting and vegetation characteristics are elaborated regarding their function in stabilizing the herbivore-vegetation system. Finally, we discuss our findings on options for sustainable pastoral livelihoods in the light of expected climate change for drylands.

2. Methods

The concept of our analysis was to investigate effects of projected climate change in drylands (Williams and Albertson, 2006; Linstädter et al., 2010), in terms of decreasing mean annual precipitation and increasing precipitation variability, on pastoral income and thereby livelihood security (Fig. 1).

Three major factors were considered to influence herd dynamics and thus income for pastoral livelihoods. First, the household type is characterized by levels of income needs and tolerable income risk. Further, the vegetation growth, specified by its rain use efficiency, determines the ability of plants to turn available water and nutritional reserves into green biomass (Le Houérou, 1984). This rate regulates the availability of forage for livestock while forage consumption feeds back on the recovery of vegetation. And third, the management of herd movements interacts with the vegetation state and may compensate for heterogeneous forage availability.

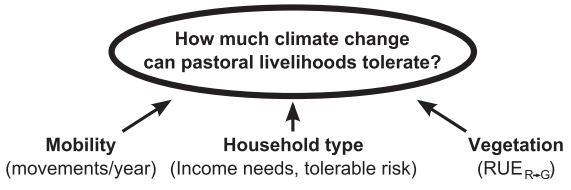

Fig. 1. The concept of our analysis with the main research question at the center and three influencing aspects considered for analysis and discussion.