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Livelihood security in face of drought — Assessing the vulnerability of pastoral households

Romina Martin[a,b,c,*], Anja Linstädter[a], Karin Frank[b,d,e], Birgit Müller[b]

[a] *Range Ecology and Range Management Group, Botanical Institute, University of Cologne, Zülpicher Str. 47b, 50674 Cologne, Germany*
[b] *Department of Ecological Modelling, Helmholtz Centre for Environmental Research (UFZ), Permoserstr. 15, 04103 Leipzig, Germany*
[c] *Stockholm Resilience Centre, Stockholm University, Kräftriket 2B, 10691 Stockholm, Sweden*
[d] *University of Osnabrück, Institute for Environmental Systems Research, Barbarastr. 12, 49076 Osnabrück, Germany*
[e] *German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Deutscher Platz 5e, 04103 Leipzig, Germany*

Abstract

Livestock grazing in drylands supports pastoral livelihoods but is facing multiple changes including shocks such as severe droughts. Herdsmen specifically cite drought events as a reason for the abandonment of their transhumance practices. The purpose of this study is to assess the relevance of drought as a driving force for losses of livelihood security leading to a specific systemic change – households abandoning transhumant pastoralism.

We present and apply a framework for systematic analyses of the social-ecological functioning of pastoral resource use that consists of the following components: (1) A spatially-explicit social-ecological model for analyzing the system dynamics, especially in face of severe drought in connection with other driving forces of variability, (2) an operationalized measure for assessing livelihood security, and (3) a strategy for systematic vulnerability assessments of pastoral households by scenario comparison. This approach is applied to the land use system of the transhumant pastoralists in the High Atlas Mountains of Morocco.

The results indicate that drought is the main threat to livelihood security in only a few cases, eventually forcing households to abandon their transhumant lifestyle. Instead, other (endogenous and exogenous) sources of variability were found to be the main driving force for vulnerability, depending on the household characteristics such as income needs and the level of pastoral mobility. We discuss implications on the role of severe drought in connection with other processes of global change such as social change and land use change for livelihood security in pastoral systems.

Moreover, on the basis of these findings, we discuss how the relevance of shocks as a driving force of systemic changes in coupled human-nature-systems may be adequately explored. These conclusions concern the interplay of exogenous and endogenous factors, and unintended side-effects of intended changes.

Keywords: social-ecological system, simulation model, semi-arid rangeland, transhumant pastoralism, Morocco, global change

*Corresponding author: `romina.martin@su.se`

1. Introduction

Drylands cover 40 percent of the earth's land surface and are home to about 30 percent of the human world population (IUCN, 2013; WRI, 2013). They are characterized by low but highly variable rainfall that strongly influences the entire dynamics (Fernandez-Gimenez and Allen-Diaz, 1999; von Wehrden et al., 2012). These harsh and unpredictable environmental conditions require a flexible and adaptive utilization of natural resources (McAllister et al., 2006). In many regions, livestock mobility, which in practice ranges from nomadic, transhumant to rotational grazing, is a key strategy for delivering sustainable land use through flexible resource usage (Brottem et al., 2014). Transhumance is the regular movement of livestock and the whole household to areas with better forage availability (Reid et al., 2008). For pastoral nomads or transhumant households, livestock-related activities are typically the main source of income (Dahl and Hjort, 1976; Breuer, 2007) and their livelihood security thus closely depends on access to forage resources.

Drylands are subject to various transformations as they are exposed to climate change, but also social, land use or institutional change (Reynolds et al., 2007). These processes can alter the conditions for pastoralism and also threaten transhumant livelihoods (Breuer, 2007). If pastoral livelihoods are no longer secure, households are eventually forced to abandon the transhumant lifestyle. It may be assumed that a systemic change affecting type of land use and livelihoods may be triggered if a critical proportion of households has abandoned transhumant pastoralism.

Drought is frequently identified as a major threat to livelihood security (see for example Scoones, 1992; Fafchamps et al., 1998; Angassa and Oba, 2008; UNISDR, 2009; UNCCD, 2010). However, drought is an ambiguous term, subject to human objectives and to the weight of emphasis on meteorological, hydrological, agricultural, or socio-economic dimensions (Thurow and Taylor, 1999; Meze-Hausken, 2004). We use the concept of a meteorological drought, defined as persistent negative precipitation anomalies, lasting several years (Méndez and Magaña, 2010; Brown et al., 2011). Defined in this way, drought is an external shock with the potential to drive a systemic change. Many studies have shown that negative effects of a meteorological drought on livelihood security can be mitigated by an adaptive risk range management, as practiced by pastoralists in drylands (Müller et al., 2007b; Linstädter et al., 2013; Mogotsi et al., 2013). Thus, a drought is a risk inherent in the system to which pastoralist economies have adapted to a certain extent (Morton and Barton, 2002). Despite pastoral societies' adaptive capacity in dealing with drought, *severe* droughts have also been shown to have - together with top-down forces of resource endowment and entitlement (Leach et al., 1999) - triggered the abandonment of transhumant practices (Thébaud and Batterbury, 2001; Turner, 2011). This underlines that even the best risk management strategy will necessarily fail if drought events are too severe. Thus, it is still an open question how relevant droughts are as a potential threat to transhumant pastoralism.

In our study, we concentrate on severe drought events which are supposed to have a high potential to threaten pastoral livelihoods. Severe droughts are a typical example for an "extreme climatic event" (ECE). For ecosystems, ECEs have been recently defined to include 'extremeness' in both the driver and the response (Smith, 2011). We transfer this concept to social-ecological systems, and consider the abandonment of transhumant practices as an 'extreme' response to severe drought when the households' adaptive capacity is overcharged. Our focus on singular, severe droughts is also in line with field observations from other pastoral systems, describing three typical stages of systemic change in Australia (Stafford Smith et al., 2007), the Sahel (Batterbury and Warren, 2001) and in southern Africa (Sander et al., 1998): A stage of good climatic and economic conditions is followed by a major drought and an inability to respond in an economically appropriate way, and then by permanent or temporary declines in grazing productivity due to detrimental feedback mechanisms between the ecological and the social subsystems of a social-ecological system.

The description of typical stages of systemic change underlines that, besides drought, other sources of variability might also affect forage availability and thereby cause a fluctuating income from livestock. As mentioned in stage three (see above), livestock dynamics are subject to variability caused by resource-consumer interactions (Illius and O'Connor, 1999; Tews et al., 2006) through plant-herbivore feedbacks. On top of these (deterministic) dynamics, natural rainfall variability is another (stochastic) source of environmental variation. It is inherent to dryland systems, and livestock and people are thus adapted to it to a certain extent (McAllister et al., 2009). However, it remains to be analyzed to what extent livestock dynamics can be attributed to these different sources of variability. This is important to identify effective response options for pastoralists.

In the present paper, we take up these debates and assess the economic vulnerability of pastoral households towards drought-induced crashes in livestock herds, but in interplay with other drivers of income variability. With this approach, we aim to provide an improved mechanistic understanding of vulnerability of pastoralists. Considering that climate change projections suggest an increased risk of more severe drought events in drought-prone dryland regions (Dai, 2013; IPCC, 2007), such an understanding is urgently needed as it is also explored via models of diverse farming systems (Bergez et al., 2013). While previous studies either investigated the dynamics of the social-ecological system of pastoralism (Janssen et al., 2000; Milner-Gulland et al., 2006) or studied economic risk in the broader context of environmental variability (McPeak, 2004; Gross et al., 2006; Quaas et al., 2007), only a few studies related the ecological threat that is posed by droughts to an economic vulnerability assessment (Smith and Foran, 1992; Hatfield and Davies, 2006).

Our exploratory modelling study thus addresses the following questions: (i) What is the role of severe drought and other sources of variability in the loss of livelihood in drylands? In other words, is severe drought really a major threat to livelihood security and key driving force for eventually abandoning transhumant practices? (ii) To what extent does the threat to pastoral livelihoods depend on the characteristics of the household? (iii) What role do income needs and the management strategy of the household play in this context? We address these questions with the case study of a pastoral system from the High Atlas Mountains in Morocco. In this case study, severe drought is perceived by the pastoralists as a major threat for livelihood security, and is frequently blamed by former pastoral households as the main reason for an abandonment of transhumant practices (Breuer, 2007). Future climate is projected to be characterized by more severe drought events (see for climate outlooks for north African drylands Paeth et al., 2009; Linstädter et al., 2010).

At the core of this paper is a novel analytical framework for systematically addressing our research questions. It is based on a process-based model which explicitly considers interactions and feedbacks between the ecological and the social subsystem (for recent social-ecological modelling reviews see Schlüter et al., 2012; Filatova et al., 2013). Apart from model building, the framework presents a strategy for systematic model analysis and the operationalization of central concepts with respect to our study (e.g. livelihood security, vulnerability to drought, abandonment of transhumant practices). By exemplary application of this framework, we provide new insights into the vulnerability of pastoral households and the role of severe drought in its interplay with other factors characteristic for drylands. We do this by step-wise testing the livelihood security as a response to the different sources of variability. Finally, we draw some general conclusions on the framework's potential to assess how shocks drive systemic change. In this way, we also aim to contribute to the discourse of principal driving forces for systemic change (with this at the core of this special issue).

2. Methods

2.1. Case study: Pastoralism as social-ecological system

The pastoral social-ecological system from Southern Morocco is situated at the southern slope of the High Atlas Mountains. This area is characterized by a steep altitudinal gradient from the Mgoun massive (4070 m asl) to the Pre-Saharan plains (1000-1500 m asl). This constitutes a climatic gradient from semi-arid to arid environments with low mean annual rainfall (150-360 mm) and high coefficients of variation (20-30%; Schulz et al. (2010)). Along the altitudinal gradient, four vegetation belts can be distinguished (Finckh and Poete, 2008; Linstädter and Baumann, 2013): semidesert, sagebrush steppe, woodsteppe and oromediterranean shrubland. Apart from arable farming in the valleys, the main source of income of the local population is traditionally generated by extensive livestock production of goats and sheep (Breuer, 2007; Akasbi et al., 2012). Depending on temporal forage availability, the livestock is moved in a transhumant manner on pasture types which roughly correspond to these four ecological zones (for more details see Linstädter and Baumann (2013) and Linstädter et al. (2013)). In the High Atlas Mountains, different types of pastoral strategies were observed during the last decade. Traditionally, nomads from the High Atlas Mountains in Morocco applied a roughly quarter-seasonal transhumance cycle (Niamir-Fuller and Turner, 1999), but through governmental restrictions and expansions of land use from adjacent villages, today they often constrain their mobility to a semi-annual cycle (Rössler et al., 2010). Furthermore the households differ strongly to what extent alternative income sources help to secure household's livelihood (Breuer, 2007). Additional income is mainly generated by wage labor and by activities in the tourism sector. These income sources support households during scarce times like those caused by droughts.

Severe droughts are perceived by the households as a major reason for the abandonment of transhumant practices (Breuer, 2007; Birgit Kemmerling, pers. comm.). However, it is unclear to what extent the drought or rather changing socio-economic conditions or changing management options resulting from less land being available are the causes for the abandonment.

2.2. Framework for assessing the vulnerability of pastoral households

Vulnerability is always a context-dependent property in the sense of "vulnerable of what towards what". In this paper, we focus on the vulnerability of pastoral households to various sources of variability intrinsic in semiarid regions (particularly severe drought, natural rainfall variability, oscillations induced by resource-consumer interactions). A household is said to be vulnerable to one of these sources of variability if its livelihood is secure in the absence of this variability, but insecure in the presence of it. We are primarily interested in the vulnerability to severe drought. To achieve comprehensive understanding, however, we consider drought as it interplays with other sources of variability and compare their relevance as driving force for the loss of livelihood security. To operationalize such a vulnerability assessment, we use an analytical framework consisting of:

1. A socio-ecological model for analyzing the system dynamics in face of different sources of variability (Section 2.3);
2. An operationalized measure for assessing livelihood security (Section 2.4);
3. A criterion for abandonment of transhumant pastoralism (Section 2.4);
4. A procedure for assessing vulnerability in a step-wise way (Section 2.5):
    - Comparison of the household's vulnerability without / with natural rainfall variability, without / with severe drought
    - Variation of various household characteristics (e.g. demands, mobility),
    - Interpretation of changes in household characteristics as indicators of social or land use change.

2.3. The social-ecological rangeland model

The model description follows the ODD protocol for describing individual-based models (Grimm et al., 2006, 2010). The first three elements provide an overview; they are followed by design concepts and the remaining elements give details on the simulation rules.

Purpose. The purpose of our rangeland model is to answer the question whether drought is actually the major threat to livelihood security in drylands and key driving force for an abandonment of transhumant practices. An abandonment of a transhumant lifestyle implies the cessation of the high mobility on a regional level that characterizes transhumance (Akasbi et al., 2012). Typically it also implies a shift from a mainly livestock-based income to an income portfolio where alternative income sources play a major role (Breuer, 2007). We therefore simulate a herd of smallstock owned by one household in a heterogeneous region driven by stochastic rainfall.

Entities and scales. Our model structure was based on difference equations that describe the production of perennial vegetation and the feedback between the herd size and the vegetation's condition (Fig. 1). The model simulated a set of equally sized pastures (each has 300 ha) where the annual production of vegetation is driven by stochastic annual rainfall. Produced biomass was distributed seasonally according to the pastures' specific distribution of rainfall during the course of the year. While earlier versions of this model used homogeneous pastures (Müller et al., 2007a; Martin et al., 2014), we parameterized a heterogeneous set of pastures according to available data from the four study sites situated along the altitudinal gradient in the High Atlas Mountains. This gradient is characterized by increasing rainfall from low to high altitudes and at the same time decreasing rainfall variability. As a consequence, vegetation differs in terms of the type, forage growth rate and capacity of standing crop. On a seasonal scale, one herd is simulated, characterized by its size which is adapted according to forage availability and herd reproduction. The herd can move between pastures seasonally.

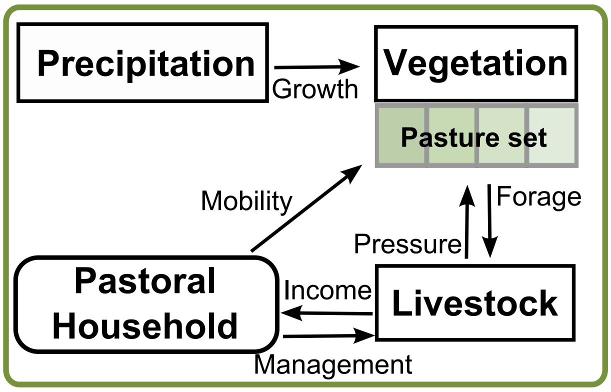

Figure 1: Causal diagram of a rangeland system showing components and processes that were simulated by our model within the context of systemic change. Livestock series were used as a basis for livelihood security assessment.

Process overview and scheduling. Prior to model simulations, rainfall series were prepared to be used in different drought scenarios. They were used as an input to drive annual vegetation growth on each pasture. The order of processes for each annual time step in the model simulations is scheduled as follows: First, we calculated the growth of forage based on annual rainfall and its distribution over seasons within one year (season length depends on mobility scenario). Second, we simulated seasonal herd movement, grazing and herd recruitment. Third, we calculated the effects of grazing on the annual recovery of reserve biomass. After model simulations are done, the resulting time series of the herd size are evaluated regarding household specific demand levels.

Design Concepts
Adaptation. Pastures adapt to environmental conditions and the intensity of grazing by building more or less volumes of reserves. Too little green biomass might hinder the photosynthetic efficiency and thus decreases the amount of reserve biomass built. This in turn effects the livestocks herd size which chooses the best suitable pasture each season and herd size is adapted to available forage if necessary. The pastoral household cannot adapt throughout the simulation since the movement frequency is fixed for each scenario.

Sensing. To evaluate the pastures state by pastoralists, the available forage is compared before each herd movement.

Stochasticity. Rainfall time series are drawn from a stochastic log-normal distribution.

Observation. As an outcome of each simulation, the time series of herd size and vegetation are recorded.

Details
Input. Annual rainfall series were generated using values from the log-normal distribution, which was specifically parameterized for each of the four pastures (different means and coefficients of variation according to series from the climate stations in the High Atlas Mountains 2001-2008 (Schulz et al., 2010)).

Initialization. The model was parameterized with data from the Moroccan case study where it was available (see Table 1). For instance ecological parameters that characterize the four different pasture types along the altitudinal gradient, such as forage growth rate and maximum standing crop, were extracted from a field study (Linstädter and Baumann, 2013). Other, more general parameters, such as mortality and growth rates of the vegetation, were estimated using the pattern-oriented modelling approach (see for this method Jakoby, 2011). That means that after parameter variation and comparison with empirical patterns, these parameters were selected to enable pastoral production in the long-run. Further scenario specification details can be found in Section 2.5.

Submodels

1. Annual rainfall with and without severe drought. We generated rainfall scenarios, including typical drought events, as a baseline to compare to scenarios with severe drought events. To define the severity of a meteorological drought, we refer to the approach of Pratt et al. (1997). Taking into account that degraded and non-degraded ecosystems respond differently to negative rainfall anomalies (Ruppert et al., 2012), they define preconditions of an 'acute' (i.e. severe) drought for both types of ecosystems. In 'healthy' (non-degraded) systems, a severe drought occurs when there is less than 25% of mean annual precipitation (MAP) over 1-2 years. In 'depleted' (degraded) systems, however, one or two successive years with less than 75% of MAP are counted as meteorological droughts. As our study system can be clearly judged as depleted due to its long history of overexploitation and degradation (Puigdefabregas and Mendizabal, 1998; Le Houérou, 2000), we use the drought definition of Pratt et al. (1997) for depleted systems.

To generate such a drought event, we draw values from the corresponding rainfall distribution for each pasture for a 200 year series, where the smallest values where checked to fulfill the criteria from Pratt et al. (1997). Deviations from MAP in these years were ca. 40% and thus sufficient to constitute a severe drought. Then, we swapped the two smallest rainfall values with those in year 60 and 61 (not earlier to exclude initialization effects in the analysis). By doing so, different scenarios and repeating stochastic runs were more easily analyzed since the severe drought always took place in the same two years. Further, the overall rainfall distribution, from which was drawn, remained the same. Multiple scenarios were executed for a set of 200 rainfall series to examine the effect of drought independently from stochastic conditions prior to the drought event.

2. Vegetation model. The purpose of our vegetation model is to simulate annual forage production in a semi-arid rangeland under the impact of grazing and variable rainfall (similar to Müller et al., 2007b; Martin et al., 2014). We focus on perennial plants and their ability to provide forage resources since the vegetation from our case study in Morocco is dominated by shrubs and perennial grasses (Baumann, 2009; Linstädter and Baumann, 2013). Perennial vegetation was simulated on the basis of two functionally complementary parts, namely green (G - photosynthetically active) biomass and reserve (R - woody) biomass (Noy-Meir, 1982). The reserve biomass quantifies storage of nutrients (Owen-Smith, 2008), which is not only influenced by rainfall but also by grazing history (O'Connor and Everson, 1998). This is congruent with previous models (Müller et al., 2007a; Jakoby, 2011). In contrast to earlier models, we assumed that shrubs may maintain green biomass into the next year and that parts of reserve biomass are palatable. We considered this to be more realistic for shrub individuals found in Morocco as opposed to perennial grasses for which the concept of reserve biomass was originally developed (Müller et al., 2007a).

Equation 1 describes the calculation of green biomass (G) in the beginning of the simulation year t including a term for growth and a term of mortality.

$$G_t\ [kg/ha] = G_{t-1} \cdot (1 - m_G) + \mathrm{rain}_t(rain_{mean}, rain_{CV}) \cdot \mathrm{RUE}_{R\to G} \cdot R_t \quad (\text{with } G_t/R_t \leq \lambda) \tag{1}$$

where G_{t-1} denotes the carry over from last year, $\mathrm{RUE}_{R\to G}$ the specific rain use efficiency for green biomass from reserve biomass in units of $kg\ G \cdot (kg\ R \cdot mm)^{-1}$, R_t the currently standing reserve biomass, and m_G denotes the fractional mortality of green biomass. The threshold λ of G/R denotes a potential of how much green biomass may grow from reserve biomass. For simplicity, we assume that the amount of green biomass growth per year is equally distributed over the seasons. While we assume no density dependence in green biomass growth, growth of reserve biomass is density dependent (Equation 2).

$$R_{t+1}\ [kg/ha] = R_t + \underbrace{w \cdot (p_t \cdot gr_1 + (1 - p_t)) \cdot G_t \cdot (1 - R_t \cdot d)}_{growth} - \underbrace{(m_R + gr_{2,t}) \cdot R_t}_{reduction} \tag{2}$$

with w denoting the recovery rate, p_t the portion of used green biomass, gr_1 the harshness of grazing which impacts the recovery of reserve biomass (value between 0 and 1, where 0 denotes a strong impact by grazing and thereby low regeneration), G_t the complete green biomass before grazing, d the density dependent factor, m_R the mortality rate of reserve biomass (value between 0 and 1), and $gr_{2,t}$ the fraction of grazed reserve biomass (value ranging from 0 to p_R which denotes the maximum part of

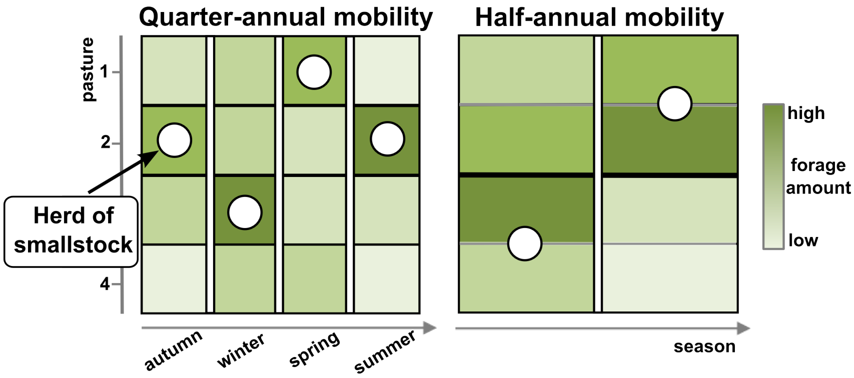

Figure 2: Intra-annual mobility of a herd on four pastures. The quarter-annual mobility utilizes each pasture for one season, the semi-annual mobility utilizes two connected pastures for two seasons before movement. Circles indicate the movement to the best pasture in each season.

palatable reserve biomass). The fraction p_t of the grazed pasture is calculated using the annual amount of grazed forage related to the previously available forage (See Eq.3 for forage calculation). Vegetation processes are computed separately for each pasture.

3. Smallstock model and herd mobility. Two strategies of pasture utilization, namely quarterly and semi-annual mobility were performed by scenarios (Fig. 2). Forage from the pasture is used by a herd of smallstock that is moved seasonally to the pasture with the highest amount of forage. The herd is destocked seasonally in case of insufficient forage and may reproduce once a year before the spring season. The amount of available forage for each season s is calculated by

$$\text{forage}_\text{s} = (G_s + p_R \cdot R_s) \cdot \text{pasture size} \tag{3}$$

where G_s and R_s are seasonally updated values dependent on previous grazing amounts. The forage demand by the smallstock herd is calculated for each season and the herd size is destocked in case the available forage is not sufficient:

$$\begin{aligned}&\text{demand}_\text{s} = \text{herd size}_\text{s} \cdot \text{season length(days)} \cdot \text{daily intake}\\ &\qquad(\text{if demand}_\text{s} > \text{forage}_\text{s} \rightarrow \text{herd size}_\text{s} = \text{forage}_\text{s}/(\text{season length} \cdot \text{daily intake}))\end{aligned} \tag{4}$$

where daily intake is assumed to be constant. Once a year animals may reproduce by

$$\text{herd size}_{s+1} = \text{herd size}_s + \text{herd size}_s \cdot b \tag{5}$$

where b denotes the annual growth rate subsuming birth and death rates.

2.4. Livelihood security assessment

Our operationalized measure for livelihood security is based on pastoralists primary goal of maintaining a 'minimum viable herd size' each year. The minimum viable herd size is defined as that size where a herd regrows fast enough after collapses such that the households are able to maintain its living dependent on livestock (Dahl and Hjort, 1976; Niamir-Fuller and Turner, 1999; LEGS, 2009). It can be interpreted as minimum income requirement. However, in such fluctuating conditions, this level cannot be met in each year and financial reserves are necessary to buffer shortages. Pastoralists differ generally in their household characteristics. In order to integrate this feature in the assessment, a household is characterized by two parameters: (1) its level of income needs τ and (2) its tolerable income risk α. A high α implies that the household has a buffer capacity with which it is able to cope with herd size shortage to a larger extent by temporary financial buffers or alternative income (Martin et al., 2014).

We define a household as secure, if the herd size of the household falls below the predefined level of income needs τ in a maximum proportion α of the years (Fig. 3). For the assessment of livelihood

Table 1: Parameters for the rangeland model with specification and default values. Sets of values differentiate characteristics of pastures along an altitudinal gradient from top to bottom. Empty cells under references indicate that the pattern-oriented modelling approach was used for parameterization

Abbreviation	Description	Values and unit	References
Pasture specific parameters			
$rain_{mean}$, $rain_{CV}$	Series of rainfall values derived from a log-normal distribution, parameterized with the expected mean and coefficient of variance	$360, 320, 240, 150$ mm, CV $0.2, 0.2, 0.3, 0.3$	rounded values based on data Sept. 2001-Aug. 2008 (Schulz, 2008; Schulz et al., 2010)
$\text{RUE}_{R->G}$	Specific Rain Use Efficiency, the specific growth rate related to the reserve biomass	$0.001, 0.001, 0.003, 0.004$ $[kg\ G \cdot (kg\ R \cdot mm \cdot a)^{-1}]$	based on production values in Linstädter and Baumann (2013)
d	Density factor of reserve biomass $= 1/K$	$1/(5000, 3000, 2000, 500\ kg)$	
R_{init}	Initial standing crop of reserve biomass	$1000, 1000, 500, 300\ kg/ha$	Baumann (2009)
$\lambda = G/R$	Maximum proportion of green to reserve biomass, capacity for green growth	$0.35, 0.4, 0.8, 1$	Baumann (2009)
General parameters			
m_G	Mortality rate of green (G) biomass per year	0.3	
m_R	Mortality rate of reserve (R) biomass per year	0.05	Schulze (2011)
w	Rate of recovery of the reserve based on green biomass	0.6	Schulze (2011)
gr_1	Disturbance of w by grazing	0.4	Müller et al. (c.f. 2007a)
p_R	Maximum proportion of palatable reserve	0.1	Baumann (2009)
b	Intrinsic annual growth rate of livestock population	0.2	
Daily intake	Amount of dry matter grazed by animals	$2\ kg/day$	Peacock (1996)
pasture size	Respective size of pastures	$300\ ha$	

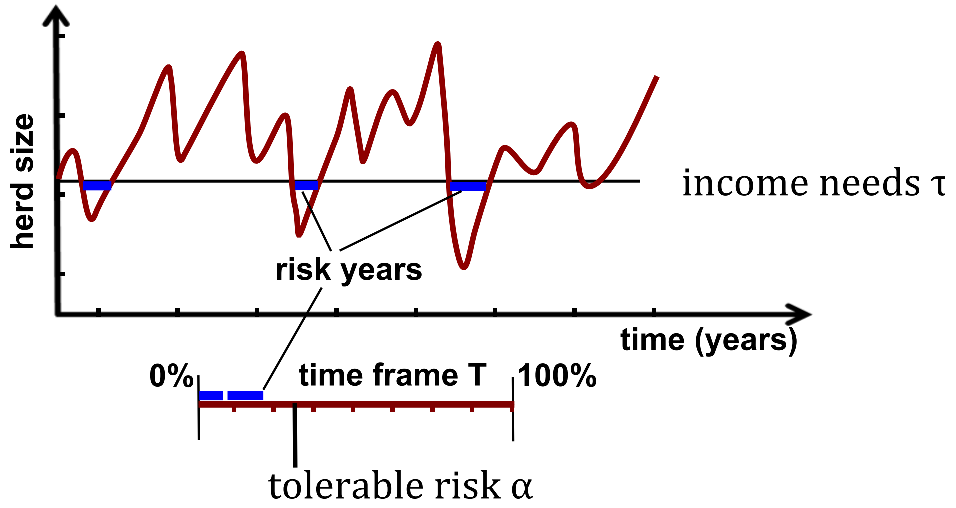

Figure 3: Draft for a livelihood security evaluation based on income from livestock. Fluctuations were evaluated by how often they cannot meet the household's demand level. Household characteristics were used as evaluation parameters: the level of income needs (τ) and tolerable risk of income undersupply (α).

Table 2: Threshold parameters for maintaining a pastoral livelihood that were used for risk assessment

Abbreviation	**Description**	**Values and unit**
τ	Threshold of income needs (herd size)	220-820
αT	Tolerable risk years	0-16 years
T	Evaluated time frame	30 years
N_{runs}	Number of stochastic runs	200

security under such stochastic rainfall conditions, two calculation steps have been carried out. First, the evaluation of one model run (a single time series of herd size) and secondly the evaluation over a number of runs with different rainfall series taken from the same distribution. In formal terms the first step is expressed as follows: We counted for each run i the number of years c_i for the interval $T = 30$ where the herd size dropped below the threshold τ:

$$c_i = |\{t : herd\ size_t < \tau\}| \tag{6}$$

Run i was evaluated as secure if $c_i < \alpha T$. To evaluate livelihood security over the ensemble of runs ($N_{runs} = 200$), we checked whether the proportion of secure runs is greater than 95%:

$$\frac{|\{i : c_i < \alpha T\}|}{N_{runs}} > 0.95 \tag{7}$$

If this equation was fulfilled, a household characterized by (τ, α) is termed as secure, otherwise as insecure. The case of a household abandoning transhumance is then defined by being secure in the baseline scenario and turning insecure in a different scenario (for instance by adding a drought). A large range of possible values (Tab. 2) were used to evaluate single time series in different scenarios of simulated herd sizes.

2.5. Model and evaluation scenarios

A pre-analysis was used to calculate the appropriate size of the pasture area to be able to maintain the minimal viable herd size of a household under average rainfall condition. We did not find consistent estimations on the minimal herd size, neither for cattle nor for smallstock herds, since this size is very sensitive towards specific socio-ecological conditions (LEGS, 2009). Dahl and Hjort (1976) assumed that a minimum of 30 livestock units, which are roughly equivalent to heads of cattle, are required in semi-arid

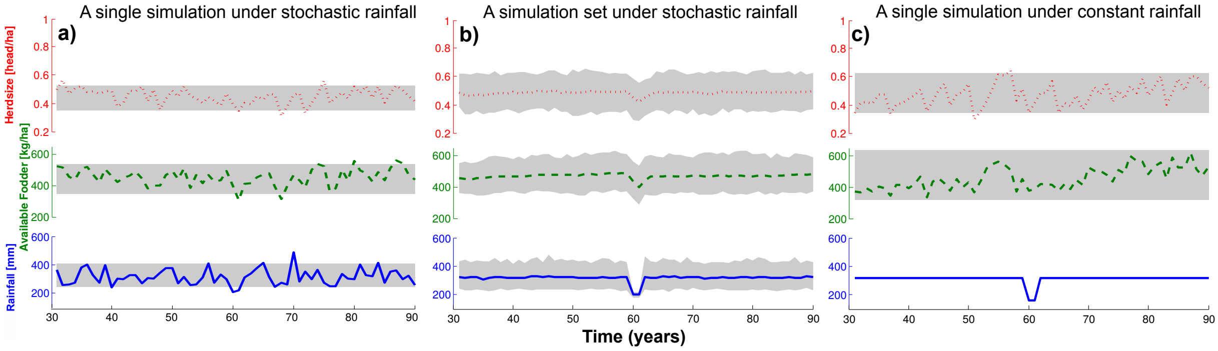

Figure 4: a) shows one example run of the herd size and fodder simulation based on a stochastic rainfall scenario with two years of drought (years 60, 61). The shaded area denotes 90% of temporal data variation. b) shows the mean results for a set of stochastic rainfall scenarios (N_{runs}=200). The shaded area denotes the confidence interval of 90% over time. This is compared to c) showing the same for one simulation under constant rainfall. The shaded area denotes 90% of temporal data variation. Note that rainfall data is shown for one out of four pastures as representative example.

regions. Following Dahl and Hjort (1976), one livestock unit equals six sheep or goats. Thus, we assume the minimum viable herd size to be $6 \cdot 30 = 180$ animals. This number is supported by empirical data on pure pastoral households in the High Atlas Mountains of Morocco (Breuer, 2007). Accordingly, we scaled the pasture area in our model to provide sufficient amount of forage for at least 180 head of smallstock. Daily intake is assumed to be constant with a value of 2 kg dry matter/day, since empirical studies estimate daily intake of sheep and goats ranging between 1 and 2.5 kg dry matter per day (Carles, 1983; Peacock, 1996).

We compared different scenarios: (1) Constant vs. stochastic rainfall, (2) with and without severe drought, (3) different management strategies, namely, quarter-annual versus semi-annual mobility. Furthermore, we conducted a robustness analysis to detect, to what extent the results depend on the level of income needs of the households and its tolerable risk.

3. Results

The main purpose of this study is to assess the relevance of severe drought as a threat to the livelihood security of pastoral households and driving force of vulnerability. To get a sound comprehensive understanding, severe drought is considered in connection with other sources of variability that might also drive the abandonment of transhumant pastoralism. Before we start with the systematic vulnerability assessment, we more closely examine the dynamics of vegetation and livestock underlying and constraining the income generation from pastoralism.

3.1. Detailed view on livestock and vegetation dynamics

First, we looked at the dynamics of herd size in time: We compared simulations of livestock under stochastic versus constant rainfall with a two-year drought event (Fig. 4). Under stochastic conditions (a, b), the drought event causes on average an immediate shortfall in available forage and thereby a decrease of the herd size. But this decrease ends with the last year of drought, so that fodder and herd size recover quickly (within two years). Under constant rainfall (c), we surprisingly observed that the herd size also fluctuates. The dynamic behavior of livestock under constant rainfall is caused by the plant-herbivore feedback. Furthermore, the data variation over one simulation in the constant case (between the 5th and 95th percentile) was very similar to the average variation per time step in the stochastic case. In spite of the constant driver, consumer-resource interaction exhibits a dynamic behavior with a similar magnitude as under stochastic rainfall.

3.2. Comparative analysis of household vulnerability to the different sources of variability

Now we go over to the main part of the study – the intended systematic assessment of the vulnerability of pastoral households to the different sources of variability, where special interest is in the dependence of the vulnerabilities on the household characteristics. In Fig. 5, each box represents one household type characterized by specific values for their demands. For example in Fig. 5 A, the herd size expectation of $\tau = 600$ without any risk tolerance ($T\alpha = 0$) was fulfilled, but not the higher demand of $\tau = 620$.

Figures 5 A-B show the livelihood state of pastoral households for the hypothetical situation that resource-consumer-interaction is the only source of variability as reference. In this case, households are found to be "secure" (medium gray cells) as long as their income needs (herd size τ) do not exceed a certain critical value or as long as their tolerance ability (tolerated risky years T_α) exceeds a certain minimum. In case of reduced mobility (Figure 5 B), the range of secure households is markedly reduced. Moreover, the positively slanted boundary line becomes steeper indicating a diminished stabilizing influence of the tolerance ability of the households. One remark: The range of the x axis - considering income needs – is above the 180 heads which was used for calibrating the pasture size. The actual size can be higher caused by different factors, for instance intended rests (caused by mobility) and unintended rests (slow growing of herd size after a drought).

When incorporating the system-immanent natural rainfall variability in the second step (Figures 5 C-D), there is a broad range of households characterized by a moderate income need τ (light gray cells) that lose their livelihood security due to this addition and become vulnerable. The range of households staying secure in face of natural rainfall variability is diminished in face of reduced mobility (Figure 5 D). If a 2-years severe drought is incorporated as last step, a surprising picture comes to light. As Figures 5 E-F indicate, there are only few households that lose their livelihood security due to this addition (dark gray cells) and become vulnerable to severe drought. This finding is independent of the degree of mobility.

4. Discussion

Pastoral households in drylands face the risk of an increased severity of droughts due to climate change (Linstädter et al., 2010). However, the relationship between severe meteorological droughts, herd size and thereby pastoral household vulnerability, is neither simple nor clear. Understanding the relationship between an external shock, such as meteorological drought, and livelihood security requires to specify how the shock's consequences propagate through the biophysical, economic and social system through which people obtain food (Dilley and Boudreau, 2001).

4.1. Relevance of drought as driving force for pastoral vulnerability

The results of our systematic vulnerability analysis indicate that in only a few cases is drought found to be the main threat to livelihood security, forcing households to abandon transhumant pastoralism. There are other driving forces of vulnerability that dominate over the effects of drought: (i) resource-consumer-interactions that cause oscillations in the herd size, even under constant rainfall and despite an adaptive stocking strategy and transhumant rotations part of the grazing management, and (ii) the natural (non-extreme) rainfall variability that is inherent in drylands. This finding is surprising given the fact that drought is frequently blamed as the most important threat to pastoral livelihoods. It is also contradictory to field observations that, in hindsight, former pastoralists see severe drought as the main driver for a households abandonment of the pastoral lifestyle (Breuer, pers. comm.). However, the perception of drought as a major threat to livelihood security may also rise as a result of an unperceived combined effect of drought and increasing demands that make many households increasingly vulnerable to the natural variability of the interaction-induced oscillations (see below Sec. 4.1.1; Pratt et al., 1997; Thurow and Taylor, 1999; Western and Nightingale, 2004; Davies and Bennett, 2007).

As a consequence of drought, we observed an instantaneous forage shortfall that was closely followed by a shortfall of the herd size by 15% under quarter-annual and 22% under semi-annual mobility. This is quite low compared to reports on 30–50% of livestock shortfalls after severe droughts in East and Central Africa (Scoones, 1992; Aklilu and Wekesa, 2002; Le Houérou, 2006). The deviance can partly be explained by the type of livestock, since smallstock like sheep and especially goats can be more drought tolerant than cattle. Smallstock browse shrubs and woody plants, rather than being confined to grasses (Grenot, 1992, browsing includes more ingestible quantity of dry matter). Thus, the buffering effect for drought transmission depends mostly on the vegetation type and well adapted herbivores. Since we simulated perennial vegetation, a large part of woody shrubs is still available as forage in years with low rainfall (c.t. Müller et al., 2007a). In contrast, most studies on droughts so far investigated areas with

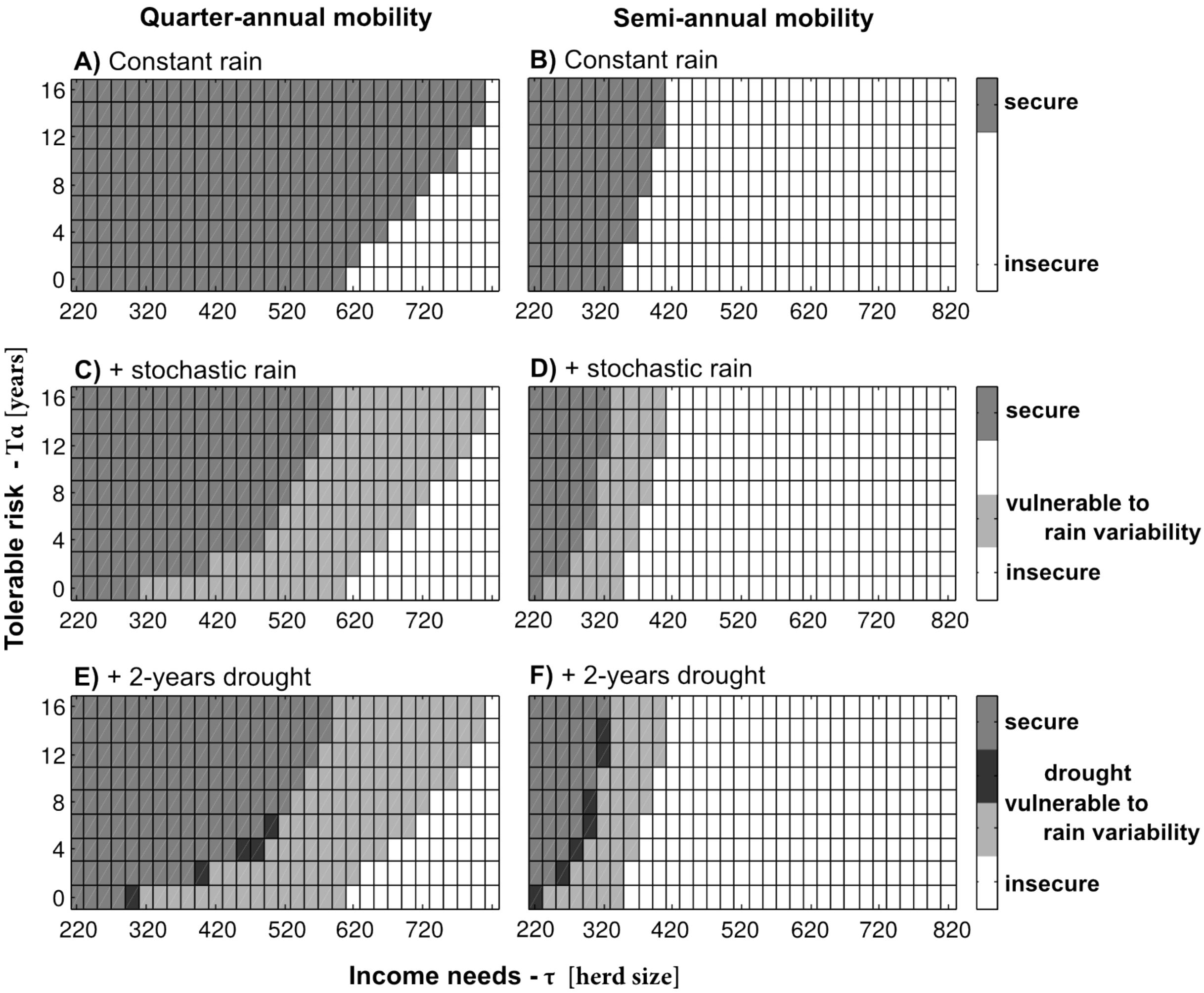

Figure 5: Vulnerability assessment of household types specified by demand levels. Herd size was evaluated as proxy for livelihood security specified by income needs and tolerable risk over 30 years ($T\alpha$). Cells with medium gray indicate demand levels which were classified as *secure* in all scenarios (e.g. without severe drought, with two years of drought). White cells indicates demand levels which were classified as *insecure* in all scenarios. Light gray cells indicate demand levels which were classified as vulnerable to rainfall variability. Dark gray indicates demand levels which were classified as insecure only in the drought scenario (*vulnerable to drought*). A) evaluates whether households are secure under constant rainfall, C) compares the first assessment with the scenario of stochastic rainfall, and E) integrates the assessment of constant, stochastic rainfall and drought scenarios. B), D) and F) show the same results for the semi-annual mobility scenario.

Table 3: Vulnerability of households depending on household characteristics and mobility strategy.

	Mobility	
	High	Low
Income needs		
Low ($\tau < 300$)	Livelihood secure, regardless of resource-consumer-interaction, rainfall variability or drought	Vulnerability to rainfall variability; livelihood security is possible provided that temporary phases of shortage are buffered; few exits in response to drought
Moderate ($300 < \tau < 600$)	Vulnerability to rainfall variability; livelihood security is possible provided that temporary phases of shortage are buffered; few exits in response to drought	Vulnerability to resource-consumer-interaction resp. rainfall variability depending on the buffer ability; no exits in response to drought
High ($\tau > 650$)	Vulnerability to resource-consumer-interaction resp. rainfall variability depending on the buffer ability; no exits in response to drought	Vulnerability to resource-consumer-interaction, even without rainfall variability or drought

cattle grazing on perennial grasses (for example Hein, 2006; Angassa and Oba, 2007) where forage and livestock shortfalls after droughts can be more pronounced.

4.1.1. Role of the household characteristics

The status and main driving force of the vulnerability of pastoral households were found to be strongly dependent on household characteristics such as income needs and the chosen mobility strategy (Tab. 3). Evidently, in a combined effect, income needs and mobility strategy also determine the extent to which a certain household can secure its livelihood through using financial reserves to buffer temporary phases of shortage. This means that the characteristics of pastoral households also shape the range of options to effectively secure livelihood. Mobility, for instance, assures temporary rests for the pastures (Müller et al., 2007a; Oba, 2012). This strengthens the regenerative ability of the pastures to the benefit of higher productivity and quicker recovery after disruption (McAllister et al., 2006; Ngugi and Conant, 2008). As a result, larger herds can be maintained and phases of shortage can be kept tolerable given the financial reserves available in the household. In other words, increasing mobility enlarges the range of grant-able income needs and increases the chance of securing livelihood using financial reserves. This is also reflected by the mobility-dependence of location and slope of the boundary lines in our vulnerability map. Consequently, we have shown that mobility has a twofold stabilizing effect as it supports both mitigation of and coping with shortages in herd size.

Especially the latter finding has serious implications for management and policy for pastoral regions. It indicates that mobility is a more effective strategy of adaptation to climate variability (incl. drought) than using financial reserves for covering temporary phases of shortage. This is in agreement with economic case studies in Ethiopia where it was shown that an increase of household vulnerability is not primarily the consequence of drought, but of uneven socio-economic drivers (Hassen, 2008). However, grazing experiments from Senegal have shown that in dry years under heavy grazing pressure, rangeland productivity was significantly reduced (Hein, 2006). This was interpreted as an indicator for vulnerability of the ecosystem and people to drought. We recommend evaluating larger time scales for the livelihood security on the household level (> 10 years) to integrate long-term trends rather than the immediate effects of droughts. The reason for households abandoning transhumant pastoralism is often more likely to be related to decreased mobility options than to the environmental hazard alone. Thus, rather than specific drought events, long-term management is decisive for rangelands productivity and thereby pastoral livelihood security.

4.1.2. Side-effects from other processes of global change on pastoral vulnerability

Our results also have implications for the debate on impacts of the interplay of severe drought with other processes of change on livelihood security in pastoral systems. We have shown that any changes in the characteristics of pastoral households can alter status and main driving force for losses of livelihood security. There are various processes of change relevant in this context: (i) social change that may alter income needs of households (Kuhn et al., 2010), (ii) economic change in form of new options for income diversification that may lower the demands on income generation from pastoralism and foster the ability to cope with phases of shortage (Breuer, 2007), or (iii) land use change that may alter mobility patterns (Kuhn et al., 2010). Note that land use change itself can have various drivers such as altered resource access regimes (institutional change), degradation (ecological change), or new technological options such as trucks (technological change). All these drivers are present in pastoral systems, interact and influence the vulnerability of households (Breuer, 2007). This shows that exclusively focusing on drought as potential driver of vulnerability is too simplistic and risks counterproductive conclusions.

4.2. Limitations of the study approach

Our study was based on a number of simplifying assumptions. It is an open question to what extent our findings are robust when relaxing these assumptions – this is a subject for future research. First, the study focused on effects of a single, severe drought Our results show that pastoral households can effectively tolerate such a singular extreme event. However, it remains unclear if frequent (less severe) droughts are functionally comparable in their effects on livelihood security. It could be argued that an increasing frequency of drought events (as expected by the IPCC (2007)) could have different, and potentially more severe effects on livelihood security which would explain why many pastoralists perceive drought as a main threat to their livelihood security. Second, our study used a vulnerability assessment at the scale of pastoral households. As all households in a certain region utilize the same natural resource basis, it can be expected that an increasing household density would negatively affect the regeneration ability of pastures. This certainly counteracts the positive effect of an increased mobility for livelihood security. Third, we neglected any costs of mobility. Accounting for them could have also decreased positive effects of mobility (see Dressler et al., 2012). Fourth, our assessment of how different adaptation strategies would affect the vulnerability of pastoral households to drought was restricted to a variation of mobility patterns. Of equal importance for household vulnerability, though, is the chosen stocking regime, such as stocking density, de- and upstocking rules (Campbell et al., 2006; Jakoby et al., 2014). Fifth, model building was oriented on our case study in the High Atlas Mountains in Morocco. This particularly concerns the assumption of a steep topographic gradient, which makes the model primarily applicable for mountain rangeland systems. However, it remains an open question to what extent our findings on the relevance of drought as driver for pastoral vulnerability depends on system characteristics such as the steepness and nature of environmental gradients.

Our debate on the relevance of drought as a driving force for the abandonment of transhumance is closely related to the debate on the conversion of a meteorological drought into an socio-economic drought (Pratt et al., 1997; Thurow and Taylor, 1999; UNISDR, 2009; LEGS, 2009; Linstädter et al., 2010). Both approaches address socioeconomic implications at the household scale of the climatic factor “drought”. However, a socio-economic drought, typically conceptualized in terms of shortage and scarcity (Linstädter et al., 2010; Drees et al., 2012) is a weaker consequence of a meteorological drought event than a complete loss of livelihood security and the consequent need to give up transhumant pastoralism, as it is explored in this paper.

4.3. Conclusions

Our study adds some valuable insights to the debate on external shocks and their relevance as driving force for systemic changes in coupled social-ecological systems. Most importantly, it revealed that drought was only under certain circumstances a severe threat to livelihood security, triggering an abandonment of transhumance. This implies that focusing on a certain type of shock (here: drought) may be too simplistic in terms of generating a sound understanding of the driving forces of a certain systemic change (here: abandonment of transhumant pastoralism). This also shows the necessity of a systemic consideration of this shock in interplay with other factors of relevance for the systemic change (here: other sources of variability).

With a respectively broadened scope of the vulnerability analysis of pastoral households, we found that there is no general answer to the question whether losses of livelihood security are endogenously or exogenously driven. We revealed that such losses may result from a complex interplay of various (endogenous and exogenous) drivers and that the characteristics of the households determine what driver is dominating. Income needs and mobility strategy were found to govern whether a certain household is already vulnerable to mere effects of the resource-consumer-interactions (endogenous driver) or only in face of rainfall variability or drought (exogenous drivers).

Drought and a subsequent loss of livelihood security are undoubtedly unintended changes for transhumant pastoralists. However, as we have learned, there can be numerous intended changes such as land use change (with consequences for e.g. mobility patterns) or social change (with consequences for income needs) which can serve as drivers for pastoral vulnerability. This shows the necessity to broaden the scope and to consider systemic changes also from the perspective of potential unintended side-effects of intended changes.

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