Which household tolerates droughts? – Strategies to secure pastoral livelihoods

R. Drees [a][b]**, A. Linstädter**[b]**, K. Frank**[a] **and B. Müller**[a]

[a] *Department of Ecological Modelling, Helmholtz Centre for Environmental Research - UFZ, 04109 Leipzig, Germany (romina.drees@ufz.de, karin.frank@ufz.de, birgit.mueller@ufz.de)*

[b] *Botanical Institute, University of Cologne, 50674 Cologne, Germany (anja.linstaedter@uni-koeln.de)*

Abstract: Increasing frequencies of droughts pose a threat to pastoral livelihoods in drylands. Using a rangeland model, we analyze the effects of droughts and mobility strategies on herd size dynamics. Since the herd provides the basic income for mobile pastoralists, we evaluate herd dynamics as income to estimate the risk of endangered livelihoods due to droughts. This methodology enables us to identify critical changes in natural resource use systems which are prone to shocks.

Model results show that the socio-economic type of the household and therewith its adaptive capacity to be mobile rather than the obvious ecological effects of droughts determine the opportunity to secure pastoral livelihoods. Concluding, we present a tool to analyze socio-economic strategies in order to detect under which circumstances a climatic shock translates to an economic crisis in pastoral livelihoods.

Keywords: livelihood security; pastoralism; dynamic rangeland model; social-ecological system

1 LIVESTOCK, LIVELIHOOD, AND SHOCKS IN PASTORAL SYSTEMS

Livestock keeping is the most important source of income in the social-ecological system of pastoralism on semi-arid rangelands [Walker and Janssen, 2002]. Shocks like droughts pose a threat to pastoral livelihoods [Fafchamps et al., 1998], and the frequency of drought years is projected to increase in north african drylands [Paeth et al., 2009; Linstädter et al., 2010]. Previous studies either investigated the dynamics of the social-ecological system of rangeland management [Janssen et al., 2000; Milner-Gulland et al., 2006] or generally analyzed the economic risk of pastoralism in a highly variable environment [McPeak, 2004; Quaas et al., 2007]. However, only few studies related the ecological risk posed by droughts to an economic risk assessment [Smith and Foran, 1992; Hatfield and Davies, 2006]. We aim to fill this gap using a simulation model and an assessment tool for livelihood security.

Droughts were often subject to research and development agencies investigating sustainable pastoralism in drylands [see for example Scoones, 1992; Angassa and Oba, 2008; UNISDR, 2009; UNCCD, 2010]. Different types of drought were specified by their level of impact as well as temporal duration, namely meteorological, hydrological and agricultural drought [Pratt et al., 1997; UNISDR, 2009]. Meteorological (ME) droughts are solely related to the duration of precipitation deficiency in comparison to an average

degree, whereas the successive hydrological and agricultural droughts are defined by the shortfall of water supply and therewith plant growth deficits. Integrating the impact on humans, socio-economic (SE) droughts occur when the demand of a natural resource exceeds the supply as a result of rainfall related supply shortfall [Linstädter et al., 2010]. In the context of pastoralism drought was generally described as a "slow-onset emergency" where a the key livelihood is lost [LEGS, 2009], meaning that only a maximum number of years with income undersupply can be tolerated.

The perception of drought consequences by pastoral herders largely depends on pasture usage and degradation [Pratt et al., 1997]. While some households may afford large distance travel with their livestock to unaffected regions [Fazey et al., 2009; Kuhn et al., 2010], for example through agistment networks [McAllister et al., 2006], others use income from non-pastoral activities [Breuer, 2007] or subsidies [Hazell et al., 2003] to provide supplementary fodder for their livestock. Although the importance of mobility for sustainable pastoralism is well known, privatization of land, tribal conflicts or governmental interventions often prevent pastoralists to make use of traditional mobility patterns [Niamir-Fuller and Turner, 1999; Oba, 2011]. However, nomadic pastoralists perceive droughts as primary cause for the loss of livestock and therewith livelihood [Breuer, 2007].

Pastoral livelihoods largely depend on income from livestock raising [Gasson, 1973]. Droughts do not only endanger income, for example from milk products, but also the assets providing income which is the livestock itself [Scoones, 1995; McPeak, 2004]. In general, the framework of livelihood security is based on adequate and sustainable access to income and resources to meet basic needs [Frankenberger, 1996]. Livelihood security was operationalized in order to evaluate household vulnerability in the context of development studies by the means of questionnaires [Frankenberger et al., 2000] but up to our knowledge it was not used to evaluate simulated income dynamics so far.

Using an abstract simulation model, we aim to identify shocks in the social-ecological system of mobile pastoralism that lead to insecure livelihoods. To parameterize and validate our model, we draw on studies from Morocco's High Atlas Mountains on rangeland ecology [Finckh and Goldbach, 2010; Linstädter and Baumann, 2012], rangeland management [Genin and Simenel, 2011; Kuhn et al., 2010] and livelihood security [Barrow and Hicham, 2000; Breuer, 2007; Rössler et al., 2010]. In Morocco, different types of pastoral strategies were observed during the last decade. Pastoral households mainly differed in their mobility and their amount of alternative income which enabled them to tolerate losses from pastoral income [Breuer, 2007]. 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 close-by villages, they often constrain their mobility to a half-annual cycle today [Rössler et al., 2010].

In the following, we present an assessment tool for livelihood security to evaluate the herd size from simulations of different drought scenarios. Our main question is: When is a ME drought translated to a SE drought which endangers pastoral livelihoods? We aim to test whether a change in mobility is more likely to endanger pastoralist's livelihood than droughts.

2 METHODOLOGY

We developed a generic rangeland model which simulates a herd of smallstock driven by stochastic rainfall. We then evaluate herd dynamics and their impact on livelihood

security to analyze the shock effect of droughts.

2.1 The rangeland model

We use rangeland model based on rules including a feedback from the herd size on the condition of the vegetation. The model simulates dynamics of perennial vegetation on a set of equally sized pastures where annual growth of biomass is driven by stochastic annual rainfall (Fig. 1). Herd size dynamics are the outcome of the model which is evaluated as pastoral income. Two strategies of pastoral utilization, namely quarter- and half-annual mobility are performed by scenarios. While earlier versions of this model implemented homogeneous pastures [Müller et al., 2007; Drees et al., in prep.], we used a heterogeneous set of pastures situated along an altitudinal gradient. This gradient results in different characteristics of rainfall and the vegetation (forage growth rate, capacity of standing crop). Hence, the model accounts for heterogeneous spatial effects of droughts.

Forage from the pasture is utilized by a herd of smallstock that is moved seasonally to the pasture with the highest amount of forage (Fig. 2). The herd is destocked seasonally in case of unsufficient forage and may reproduce once a year. We compare the quarter-annual against the half-annual movement strategy in terms of the sustained herd size. Rainfall series were generated by draws from the lognormal distribution. In order to
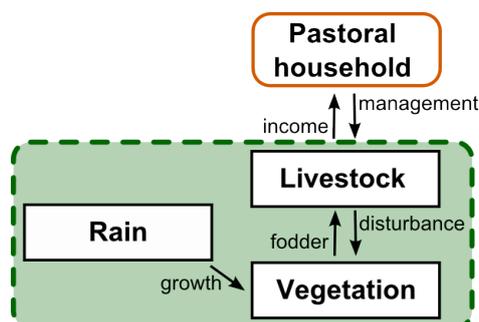

Figure 1. Causal diagram of a rangeland system showing components (boxes) and processes (arrows) that are simulated by our model.

investigate different length of a meteorological drought, we built drought scenarios by permuting a certain number of minimum rainfall values to a fixed point in time (t=60, to exclude initialization effects). This was done for a set of 500 rainfall series to examine the effect of droughts independently from stochastic conditions. Parameters for mortality and growth rates of the vegetation were calibrated through filtering realistic parameter ranges that enabled sustainable pastoral production. We excluded parameter ranges that would lead to degradation in the current system since we were interested in the drought induced risk only. 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, 2012].

2.2 Livelihood security assessment

Pastoral livelihoods on the household level are based on income from pastoral activities [Frankenberger, 1996; Scoones, 1998]. Although needs and activities in pastoral house-
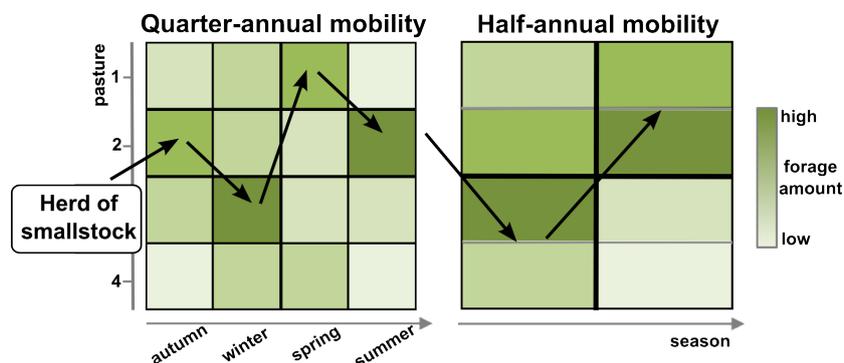
Figure 2. Intraannual movement of a herd on four pastures. Practicing quarter-annual mobility utilizes each pasture for one season while practicing half-annual mobility makes use of two connected pastures for half a year.

holds are manifold and complex, it is appropriate to assume that pastoralists seeks to support and fulfill a certain threshold of herd size (see concept of minimum viable herd size) [Niamir-Fuller and Turner, 1999; LEGS, 2009].

We developed a risk assessment scheme to evaluate herd size dynamics taking into account two dimensions of risk attitude (demand levels) by households (Fig. 3). The first dimension depicts the level of income needs by one household (τ), while the second dimension accounts for the tolerable income risk over time (α). The first, τ, specifies a level of income needs via an expected minimum viable herd size which is a threshold that needs to be fulfilled. The second, α, denotes the proportion of years where the herd size drops below τ, as a measure for the tolerable income undersupply. Pastoralists may tolerate income shortfall from livestock during some years when they have alternative income sources from non-pastoral activities. Hence, we are able to discriminate herd dynamics whether they would fulfill the household's demand levels over time or not and thus identify this household as safe. Since we evaluate a set of 500 simulations driven by stochastic rainfall, demand levels were classified as secure when in more than 95% of simulation runs thresholds were met.
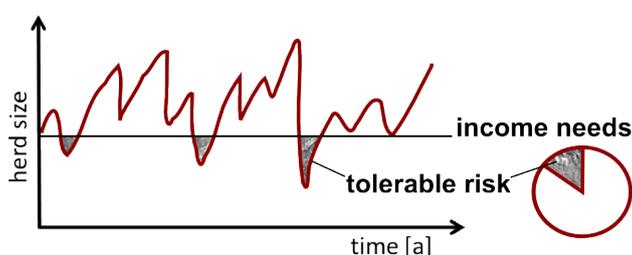

Figure 3. Livelihood security based on income from livestock. Herd size dynamics are evaluated by how often they cannot meet the household's demand: the level of income needs and tolerable risk of income undersupply (proportion of SE drought years).

3 HERD SIZE DYNAMICS

We simulated three drought scenarios and one no-drought scenario, each one for 500 simulations. The purpose of the scenario comparison was to investigate how a ME drought generally translates to herd size dynamics and a SE drought.
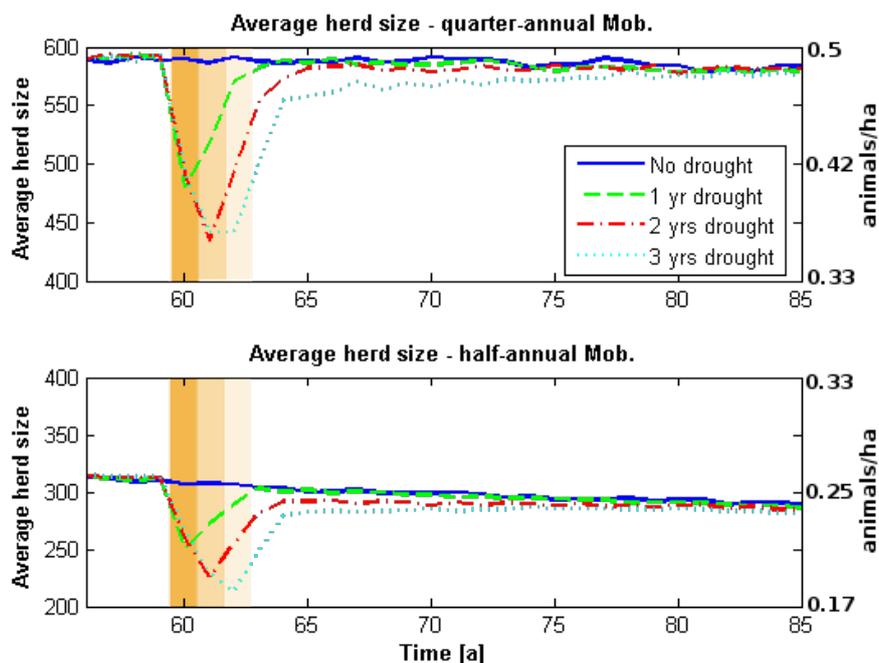

Figure 4. Average herd size (head of smallstock, sheep or goats) over 500 simulations from a scenario of no drought, one year, two years or three years of ME-drought starting in the year 60 (bars). Two mobility strategies are compared (A: quarter-annual mobility, B: half-annual mobility).

In all scenarios average herd size decreased during the drought years for both mobility strategies (Fig. 4). However, applying the half-annual mobility resulted in lower values and a trend of degradation. The recovery time after the end of the drought to reach pre-drought herd sizes was also prolonged under the half-annual cycle.

3.1 Pastoral households affected by drought

In order to assess the effect of ME droughts on livelihood security, we evaluated each run based on our risk assessment. We were interested to identify demand levels which enable pastoral households to traditionally survive on their herd but who are endangered when facing a drought. Fig. 5 shows these demand levels in red, as they were judged to be safe in the no-drought scenario but not in the two-year-drought scenario.

Further, we were interested in how much the secured demand levels change with the applied mobility strategy. Although the same size in pasture area is utilized, the half-annual cycle resulted in much lower levels of the sustained herd-size. In terms of livelihood security, less levels of income needs were sustained by both a no-drought or two-year-
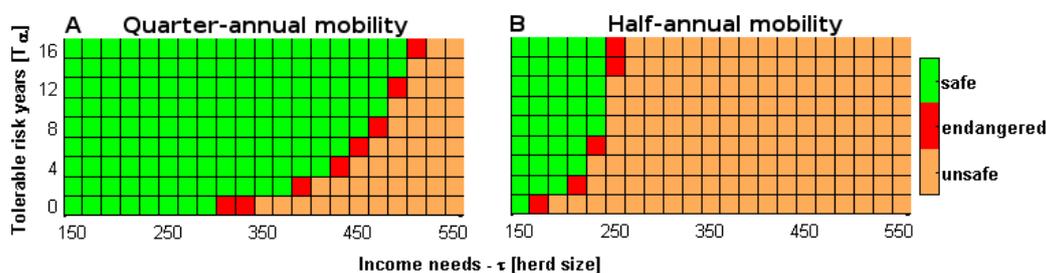
Figure 5. Household evaluation of livelihood security based on income needs and tolerable risk over 30 years (T α). Green grid fields indicate demand levels which were classified as *safe* in both scenarios (without drought, with two years of drought). Orange indicates demand levels which were classified as *unsafe* in both scenarios. Red indicates demand levels which were classified as unsafe only in the drought scenario (*endangered*). Subfigures A and B contrast two mobility strategies.

drought scenario (marked green). Using alternative income in order to increase the level of tolerable risk (years with income undersupply) is more likely to improve the secured income from livestock when applying the quarter-annual cycle.

Having no alternative income resulted in a sustained herd size of 330 under the quarter-annual cycle. Less than 55% of the herd size was sustained applying the half-annual cycle. Two years of drought endanger less than 10% of the herd size which was secure without the drought.

4 DISCUSSION AND CONCLUSION

The social-ecological system of pastoral range management faces the risk of an increased frequency of droughts in drylands due to climate change [Linstädter et al., 2010]. However, the relation of meteorological droughts to shortfalls of herd size and therewith a socio-economic drought and livelihood risk was not clear so far.

We presented a combination of simulation modelling and risk assessment to identify management strategies and household traits that allow secure livelihoods. We aimed to test whether droughts endanger livelihoods more or less than a decreased mobility. Our results have shown that herd sizes that were sustained by the quarter-annual cycle, decreased by 40% compared to herd sizes resulting from the half-annual cycle. Only a maximum of 10% of income was endangered by drought, thus the choice of the mobility cycle had a much larger effect than a drought period.

Mobility was often discussed as a critical strategy for pastoralists in drylands [Oba, 2011], either by escaping the effects of droughts through large scale movements to unaffected areas [McAllister et al., 2006] or by tolerating drought and using local key resources as buffering forage stock [Ngugi and Conant, 2008]. A change of pasture access regimes is a likely threat in Morocco due to expansion of close-by villages as well as governmental interventions that seek to provide incentives for pastoralists to become sedentary [Breuer, 2007]. Since it seems obvious that the herd size is decreased by limiting the absolute size of pastures, we made an even stronger argument: Although the absolute pasture size remains, our model has shown that the management strategy alone makes a big difference. This was also observable in Morocco, where poor households have fewer labor force and cannot afford to apply the full transhumance cycle anymore [Rössler et al., 2010]. Our results support that decreasing mobility could have more negative impacts

on pastoralists livelihood security than a meteorological drought.

Drought was often seen as a trigger for the collapse of pastoral households [Breuer, 2007]. However, the perception of droughts may also rise as a result of an increased food and income demand due to population growth or as a result from land use change [Pratt et al., 1997; Western and Nightingale, 2004].

We conclude that a meteorological drought alone does not endanger most pastoral livelihoods. Concurrent population growth as well as restricted mobility, because of diverse socio-economic reasons, pose a far greater risk [Davies and Bennett, 2007; McAllister, 2010]. Keeping climate change responsible for drought induced risk of livelihoods is misleading when instead political action is required to ensure adequate access regimes to pastures or markets for growing populations of people.

ACKNOWLEDGMENTS

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APPENDIX

Equations and parameters used by our model: Equation 1 describes the calculation of green biomass in the beginning of the simulation year t including a term for growth and a term of mortality.

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

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 $kg\ G \cdot (kg\ R \cdot ha \cdot mm \cdot a)^{-1}$, R_t the currently standing reserve biomass, and m_G denotes the mortality of green biomass (value ranging from 0 to 1). The threshold λ of G/R denotes a capacity of how much green biomass may grow from reserve biomass. The distribution of growth each season is assumed to be proportional to the seasonal rainfall distribution. While we assume no density dependence in green biomass growth, growth of reserve biomass is density dependent (Equation 2).

$$R_{t+1} = R_t + \underbrace{w \cdot (p \cdot gr_1 + (1-p)) \cdot G_t \cdot d \cdot R_t}_{growth} - \underbrace{(m_R + gr_2 \cdot R_t)}_{reduction} \qquad (2)$$

with w denoting the recovery rate, p the part of the grazed pasture, gr_1 the harshness of grazing which reduces the recovery of reserve biomass (values ranging from 0 to 1, where 0 denotes a strong impact by grazing and therewith low regeneration), G_t the complete green biomass before grazing, d the density dependent factor, m_R the mortality rate of reserve biomass (values ranging from 0 to 1), and gr_2 the partition of grazed reserve biomass (value ranging from 0 to R_p which denotes the maximum part of palatable reserve biomass). The partition p of the grazed pasture is calculated using the amount of grazed forage related to the previously available forage. Vegetation processes are computed separately for each pasture.

The amount of available forage for each season t is calculated by

$$\mathrm{forage_t} = (G_t + R_p \cdot R_t) \cdot \mathrm{pasture\ size}. \qquad (3)$$

The forage demand by the smallstock herd is calculated for each season and the herd size is adjusted in case the available forage is not sufficient.

$$\mathrm{demand_t} = \mathrm{head\ of\ smallstock_t} \cdot \mathrm{season\ length} \cdot \mathrm{daily\ intake}$$
$$(\text{if } \mathrm{demand_t} > \mathrm{forage_t} \to \mathrm{head\ of\ smallstock_t} = \mathrm{forage_t}/(\mathrm{season\ length} \cdot \mathrm{daily\ intake}))$$
$$(4)$$

where daily intake is assumed to be constant with a value of 2 kg dry matter/day, while empirical studies estimate daily intake of sheeps and goats ranging between 1 and 2.5 kg drymatter per day [Carles, 1983; Peacock, 1996]. Once a year animals may reproduce by

$$\mathrm{animals}_{t+1} = \mathrm{animals}_t + \mathrm{animals}_t \cdot b \qquad (5)$$

where b denotes the annual growth rate (recruitment - mortality).

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.

Parameter	Description	Values and unit
$Rainfall_t$	Dataset with MAR values derived from a log-normal distribution, parameterized with the expected mean and coefficient of variance	$360, 320, 240, 150 \quad mm$, CV $0.2, 0.2, 0.3, 0.3$
$\mathrm{RUE}_{R->G}$	Specific Rain Use Efficiency, the specific growth rate related to the reserve biomass	$0.001, 0.001, 0.003, 0.004$ $[kg\ G \cdot (kg\ R \cdot ha \cdot mm \cdot a)^{-1}]$
m_G	Mortality rate of green (G) biomass per year	0.3
m_R	Mortality rate of reserve (R) biomass per year	0.05
w	Rate of recovery of the reserve based on green biomass	0.5
gr_1	Disturbance of w by grazing	0.5
d	Carrying capacity of reserve biomass $= 1/K$	$1/(5000, 3000, 2000, 500\ kg \cdot ha^{-1})$
R_{init}	Initial standing crop of reserve biomass	$1000, 1000, 500, 300 \quad kg \cdot ha^{-1}$
$\lambda = G/R$	Maximum proportion of green to reserve biomass, capacity for green growth	$0.35, 0.4, 0.8, 1$
R_p	Maximum proportion of palatable reserve biomass, actual values stored in gr_2	0.1
b	Intrinsic annual growth rate of livestock population	0.2
$Daily \quad intake$	Amount of dry matter grazed by animals	$2\ kg/day$
W	Respective pasture size	$300\ ha$