Ecological vulnerability through insurance? Potential unintended consequences of index-based livestock insurance

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Abstract:

Increasing droughts pose one of the greatest challenges for dryland pastoralists in the Horn of Africa. To manage drought risks, weather index insurance has been proposed and with the Index-Based Livestock Insurance a pilot programme has been introduced in 2010. In this paper, we study the long-term effects of weather index insurance on pasture conditions with the help of a stylized agent-based model. We hypothesize that if insurance is taken up at scale, the maintained high grazing pressure can cause pasture degradation. Our results show that especially under harsh grazing conditions, insurance can indeed produce additional instability and engender pasture degradation that results in a lower carrying capacity in the long run. Unfortunately, the unintended ecological consequences are most likely where insurance is needed the most.

Keywords: weather-index insurance, risk-coping strategies, drought, pastoralism, grazing, East Africa

JEL classification: G22, O13, Q12, Q14

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1. *Introduction*

Increasing droughts are identified as one of the greatest challenges among pastoralists in drylands (McPeak et al. 2011, Alemu and Robinson 2015). Highly variable rainfall, both in terms of inter-annual and intra-annual variability, causes large fluctuations in resource availability, and thus, often renders stationary land-use options like agriculture or sedentary livestock breeding difficult. Therefore, mobile livestock keeping is often identified as the best-suited land-use strategy, as it can quickly adapt to changes in the available resources (McGahey et al. 2007).

The Horn of Africa has very large inter-annual rainfall variability where tens of millions of people derive their main livelihood from mobile pastoralism. Even though droughts have always been an inherent feature of these arid and semi-arid regions, their numbers and repercussions have increased in recent years due to climate change (Niang et al. 2014). Droughts cause forage scarcity, and thus, often entail livestock losses. Between 1980 and 2001, recurring droughts killed 37 to 62% of all cattle in the Borana Plateau of South Ethiopia (Desta and Coppock 2002, Jensen et al. 2014). As a consequence, people often starve and can be caught in poverty traps (Lybbert et al. 2004, Toth 2015). These poverty traps are induced a critical minimal herd size under which mobile pastoralism is not viable. Since reproduction is also low for small herds, people are trapped in a destitute situation.

Insurance has emerged in the last decade as an increasingly popular instrument among policymakers to manage drought risks. Most insurance schemes in rural areas in developing countries are index-based (hereafter referred to as weather index insurance) which means that a payout is triggered if a predefined threshold of rainfall or vegetation cover is not met. This saves case-by-case damage assessments, and hence, greatly lowers the cost of product delivery. In Kenya and Ethiopia, a pilot programme called Index-Based Livestock Insurance (IBLI) has been introduced in 2010 and is being closely monitored ever since (Chantarat et al. 2013). IBLI relies on an index of remotely-sensed vegetation data (i.e. Normalized Difference Vegetation Index, NDVI). A payout is determined based on how much current vegetation data lie below a threshold that is defined based on long-run average conditions. In the original *asset replacement* design, the index on which payouts were based predicted average livestock mortality. Hence, payouts were made shortly after the drought, i.e. when losses had already occurred. Advancements in vegetation forecasting made it possible to predict dry-season forage availability already during the growth period. This also allowed shifting payouts to before the (predicted) drought sets in, so herders may prevent losses, e.g. by purchasing supplementary fodder from unaffected regions (*asset protection* design).

In this paper, we analyse the long-term effects of weather index insurance. We hypothesize that, if insurance is taken up at scale, it can cause pasture degradation. The main mechanism is as follows. In order to avoid livestock loss and its socio-economic consequences, both insurance concepts (asset replacement and asset protection) aim to maintain livestock numbers at pre-drought levels, or restore them to those levels as quickly as possible. Pastures, on the other hand, are usually in bad conditions after a drought and need some time to recover. In that regard, livestock losses during a drought create a "natural resting period" in absence of insurance. If, for a significant share of pastoralists, livestock losses are prevented through insurance, these post-drought resting periods will diminish. So, over time, pastures may slowly degrade. So, while at the individual level, it may be optimal to cushion the immediate effects of a drought by purchasing insurance, on an aggregated level, however, this may lead to unsustainable over-use of pastures.

To test this hypothesis, we developed a stylised agent-based model (ABM) that is adapted in a stylized way to the conditions faced by Borana pastoralists in South Ethiopia and North Kenya.

This modelling approach can overcome two shortcomings which cannot be solved otherwise: First, it enables us to observe processes that would materialize only in the medium and long run and for which there is currently no empirical data, since there is no index insurance programme that has operated at significant scale for more than 5-10 years. Thus, with our model we can point to potential unintended consequences before they become reality. Second, it is possible to use the model as a "virtual lab". In it we explore different scenarios (e.g. different ecological conditions or rainfall values) and analyse their effect. Due to the stylized nature of our model, it is not possible to quantitatively predict livestock numbers for any specific region or year. Accordingly, we aim at highlighting structural, qualitative changes in system dynamics.

The model depicts a Borana settlement (*olla*) which consists of 10 households who move their herds back and forth between wet and dry season grazing areas. Hence, this study extends existing models in several ways: By including different pasture types, grazing dynamics can be modelled more realistically. Several studies have highlighted the importance of resting (e.g. Müller et al. 2007), which pastoralists can do explicitly by deliberately choosing not to take their herds to a pasture if it is in a bad condition. By making herd movement explicit, we can differentiate between wet season grazing areas where usually all herds of the settlement graze together and their dispersal onto different dry season grazing areas. Furthermore, by employing a dynamic simulation model we can depict the nonlinear interactions between consumers (livestock) and resource (biomass) dynamics as well as the impact of economic decisions (insurance).

Previous studies on the impact on weather index insurance focus primarily on direct economic impacts at the beneficiary level: Mobarak and Rosenzweig (2013) found that Indian farmers who are insured against weather risks take significantly less action to mitigate risks. Cole et al. (2016) similarly showed in field experiments that, with insurance, farmers shift their production to crops with higher yields, but also higher sensitivity to rainfall. Ghanaian farmers with insurance additionally invested significantly more in agriculture (Karlan et al. 2014). Other work strives to explain low uptake rates of weather index insurance in drylands (Binswanger-Mkhize 2012, Mobarak and Rosenzweig 2013, Karlan et al. 2014, Cole et al. 2016) and basis risk (Jensen et al. 2014, 2016).

Analysing how IBLI helps manage drought shocks, Janzen and Carter (2013) found that policy holders are considerably less likely to sell livestock and to cut back on their current food consumption. Jensen et al. (2016) report that IBLI coverage reduces households' exposure to risk from large covariate shocks by roughly 63%. These results show that IBLI is effective in cushioning immediate effects of droughts. The long-term effects, however, have not been studied so far, mainly due to lack of data.

The interplay of insurance with ecological factors is mainly analysed in theoretical models: In a generic analytical model, Bhattacharya and Osgood (2014) elaborate two distinct effects that arise from insurance: a substitution effect and an income effect. The former refers to households diverting resources from their production activity towards the insurance premium. In pastoral systems, this reduces pressure on the common property resource (i.e. the pasture). The income effect, on the other hand, follows from the insurance payout in case of a drought, which increases farmers' well-being and can prevent them from dropping out of the system. For pastoral systems, this could lead to an increase of environmental pressure, as the natural self-correcting mechanism of outward selection is muted. They conclude that it remains an empirical question which effect will be stronger. Müller et al. (2011) assess the effects of weather index insurance for a single private-property livestock farmer in a dynamic simulation model. They show that setting the strike level (the threshold that triggers a payout) too high, creates incentives to use the land in a less sustainable way and therefore advocate insuring only severe droughts.

Our results show that especially under harsh grazing conditions, insurance can produce additional instability and engender pasture degradation that results in a lower carrying capacity in the long run.

The remainder of this article is structured as follows: In the next section, we introduce our model and explain our analysis methods. In section 3, we present the main findings from our simulations, which we discuss in section 4. Finally, we draw some conclusions.

2. *Methods*

To analyse the effects of weather index insurance, we used a social-ecological agent-based model which we will briefly introduce before describing our analysis methods.

Model description

Overview

Figure 1 shows the overall structure of the model which is aligned to the Borana ethnic group of South Ethiopia/North Kenya. It depicts the rangeland practices of a pastoralist settlement and runs in discrete quarter-annual time steps. This temporal resolution follows the four weather seasons over the year: long rain (Apr - Jun) - long dry (Jul - Sep) - short rain (Oct - Dec) - short dry (Jan - Mar).

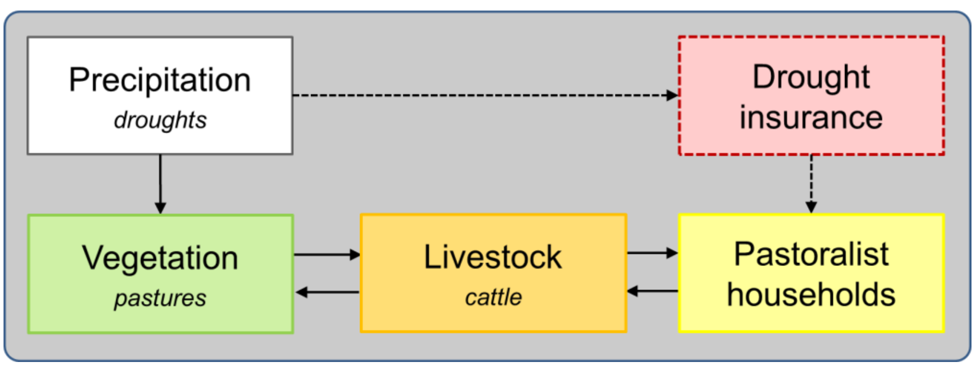

Fig. 1: Model structure

Agents are homogeneous households who keep cattle and move their herds back and forth between rainy-season pastures near the settlement and several remote dry-season pastures. Site selection is based on the biomass available on each pasture. Herds feed on grass and reproduce once a year with a constant growth rate. If a pasture does not provide enough fodder to sustain the entire herd, surplus animals have to be sold. Since, in rainy seasons, all animals share the grazing areas near the settlement, agents destock their herds in equal proportions if need be.

The vegetation of each patch resembles a generic type of perennial grass with two components: green and reserve biomass. Green biomass comprises the photosynthetically active parts like leaves and is consumed by the animals. It sprouts from reserve biomass – the brown storage parts above and below ground like roots and stems – depending on rainfall. Additionally, (unconsumed) green biomass contributes to the accumulation of reserve biomass in the next year.

According to empirical observations (Toth 2015), a critical herd size is needed for mobile pastoralism to be viable. Whenever an agent falls below that threshold, they become sedentary throughout the year and are exempted from destocking as long as others have larger herds. Agents without any animals are forced to abandon pastoralism and leave the system.

Insurance

To this baseline model, we added an insurance feature. When it is active, all mobile households will purchase insurance for a specified amount of animals each year (or less if their herds are smaller). We are aware that this assumption might seem far-fetched considering the current low uptake rates (e.g. Binswanger-Mkhize 2012). The aim of this study, however, is to show potential long-term effects if pastoralists did have such insurance. Therefore, we think making this assumption is justified.

The insurance is actuarially fair and is purchased at the beginning of each year. When rainfall remains below a certain threshold, agents will receive a payout at the end of this year – regardless of their actual losses. If agents lose animals they will use the payout to restock, otherwise they store it to pay future premiums.

For a complete description of the model please refer to the ODD+D protocol in the appendix.

Initially, we had intended to draw rainfall from a random distribution, make agents heterogeneous in their initial herd sizes, and use a stochastic herd growth function. However, this made it very hard to separate noise from signal, especially since the livestock and biomass trajectories showed a great deal of path-dependence. Fig. 2 shows an example of two simulation runs with (turquoise graph) and without (red) insurance based on the same random seed.

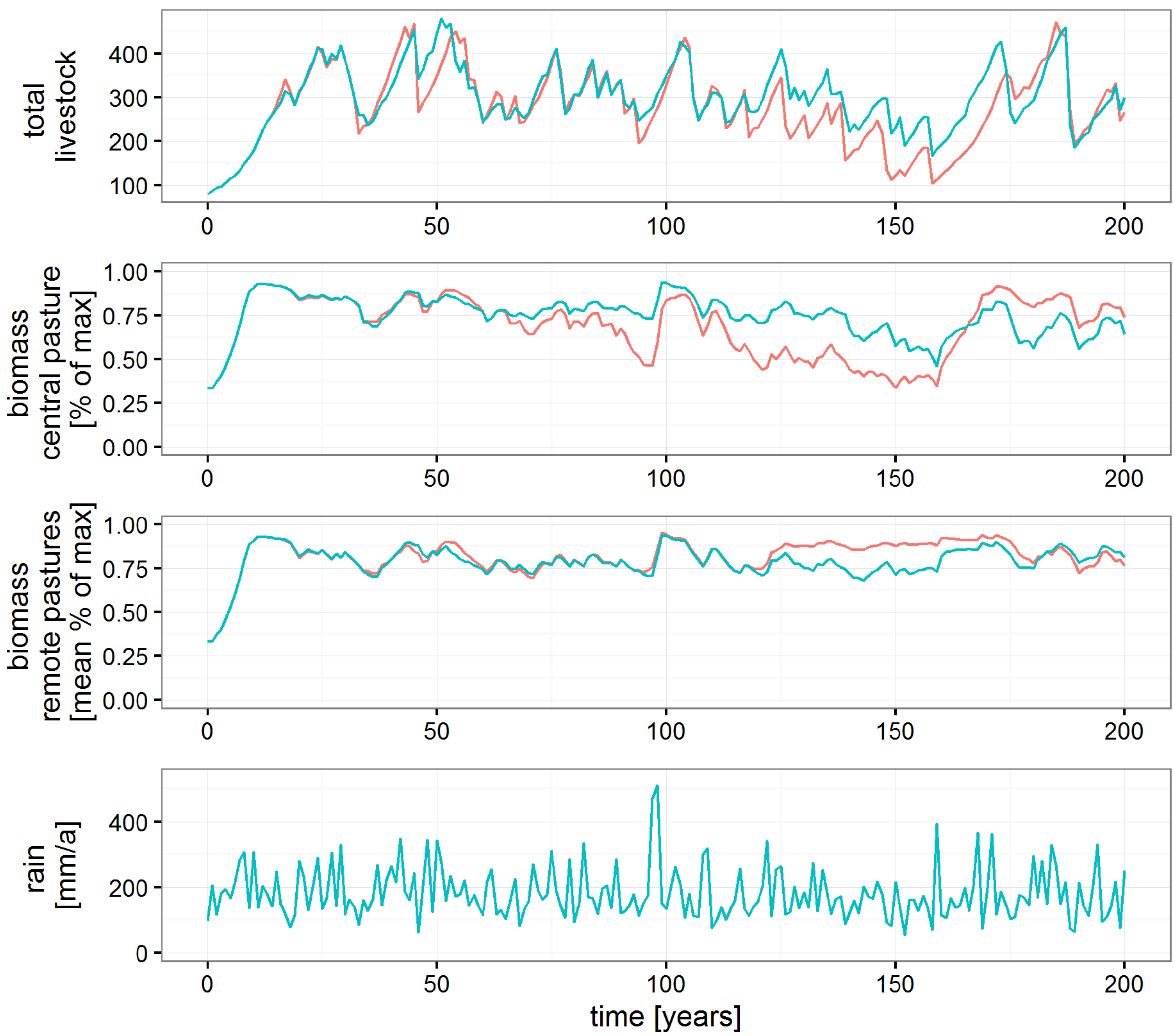

Fig. 2: Development of livestock numbers, biomass and rainfall over time for random rainfall. Scenarios represent the situation without insurance (red graph) and with an insurance of 5 TLU (blue graph), grazing harshness is medium (gr_1 = 0.5) and both simulations are generated with the same random seed. Biomass values are normalized to the maximum reserve biomass.

So, for analytical reasons, we had to reduce model complexity in different ways: We switched to deterministic livestock reproduction and homogeneous herders. Highly variable rainfall, on the other hand, is a system-immanent feature of semi-arid rangeland areas around which these systems evolved. Based on a historical 47-year rainfall data set from Laisamis, Marsabit County, North Kenya, we inferred that rainfall approximately follows a lognormal distribution. As a compromise between natural variability and analytical clarity, we drew six representative rainfall values from the random distribution. We made sure that this sample included exactly one drought and was similar in terms of sample mean as well as standard deviation. Then we created three different sequences. In our simulations, we continuously repeated this sequence as shown in fig. 3.

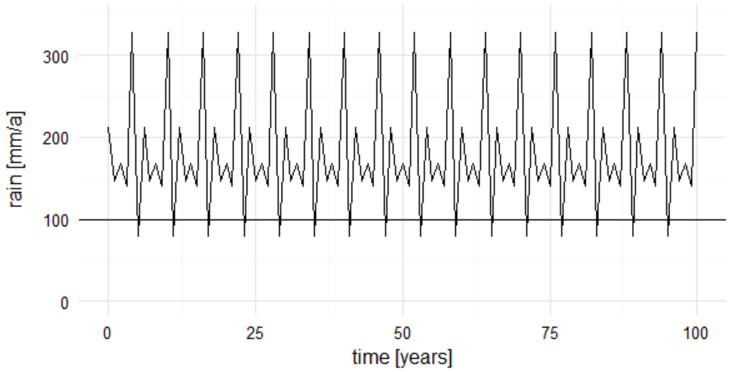

Figure 3: Rainfall time series generated from a repeated 6-year sequence of rainfall values (here in the order with the highest negative autocorrelation).

As is commonly done in time series analysis, those combinations are chosen that depict extreme cases in terms of temporal autocorrelation. These extremes can also be assumed to cause the most diverse system dynamics. The chosen rainfall scenarios are: ascending and descending order (yielding the highest positive autocorrelation) as well as a strongly alternating rainfall pattern (highest negative correlation). Although we analysed all three patterns, here we only present the results for descending and fluctuating rainfall. Ascending rainfall led to qualitatively similar results.

Model analysis

We analysed the effects of both economic and ecological parameters. On the economic side, we varied an insurance sum from 0 to 50 animals. Since herd sizes never exceeded 50 animals, this is equivalent to insuring the entire herd. Note that the insurance sum is the maximum amount of animals that herders would ensure, but they never insure more animals than they actually have. On the ecological side, we varied the pasture regeneration capacity from grazing. If it is 1, grazing does not have any impact on the pasture development; if it 0, only biomass that is not consumed by animals, contributes to biomass growth.

We then run the model for 1000 time steps (= years). This time span is, of course, unrealistically long, but we do this mainly to see whether patterns stabilise. To compare scenarios, we evaluate results against two criteria: (i) the long-term mean of livestock numbers and (ii) the downside risk. For the former, we take the total number of livestock and calculate its mean over the last 900 time steps. By comparing it to the scenario without insurance, we thus isolate the long-term effect of insurance on livestock numbers. This metric, however, ignores variation over time, which is why we also analyse the downside risk. Downside risk measures the standard deviation of only those values that are below a critical threshold, in our case the long-term mean of livestock numbers. In other words, downside risk indicates how likely it is to fare worse than without insurance. Focussing on potential losses makes sense if one assumes that livestock keepers tend to be risk-averse.

We are aware that both measures are based on livestock numbers. However, since most other variables can be traced back to the impact of livestock (e.g. low biomass can support fewer animals and herds would always grow until they reach the carrying capacity of the pasture), this focus seems reasonable.

A check for inter-run variability revealed that the model produces identical results regardless of the random seed. Therefore, we run the model only once for each parameter constellation.

Additionally, we analyse the main drivers of the system dynamics. For that, we cut off the first 100 time steps of each simulation considering them the transient phase. Over the remaining 900 time steps, we conduct a Fourier transformation of the livestock time series. A Fourier transformation is a method from physics that decomposes a time series into the frequencies that it is made up of. It does so by fitting sinusoidal waves of different lengths into the original time series. Thus, it converts a function of time into a frequency domain.

Based on the dominant frequencies, we classify three system orders:

1. *Collapse*: Either at least one household was forced to leave the system (because all their livestock had died and they did not have the means to buy new animals) or during the last 100 years of the simulation there was always less than 1 animal in the system (i.e. all households had between 0 and 1 animals). This means that, on average, each agent has less than one animal. A herd size this small has shown not to recover.
2. *Oscillation*: There was at least one frequency in the band of $0.005 < f < 0.025$ (i.e. wavelengths between 40 and 200 years) that had an amplitude of at least 400 000.

3. *Stability*: Variables fluctuate on a small scale within a constant interval (i.e. all runs that do not fall in any of the other categories).

These frequencies enable us to draw conclusions about dominant drivers. In stable systems, fluctuations are small and mainly due to rainfall variability. Oscillating systems, on the other hand, display strong long-term fluctuations that go well beyond the effects of rainfall variability. Usually, they take the form of a creeping degradation of pastures and livestock. Finally, collapse indicates that the entire pastoral rangeland system breaks down.

3. Results

In this part, we are first going to describe the temporal dynamics for individual runs and then compare the results of different parameterizations of the model.

Temporal dynamics

In ecosystems where grazing has a low impact on vegetation growth, our simulations show that livestock follows boom-and-bust cycles (fig. 4, red graph). They are frequently observed in reality (e.g. Desta and Coppock 2002) and describe a steady herd growth that is repeatedly interrupted by shocks. It can also be seen that these drops correlate with drought years. In other words, the system is primarily driven by rainfall variability.

Introducing insurance in this context (fig. 4, blue graph) slightly changes the dynamics: In our simulation, insurance is introduced after 15 years, and we see that dynamics slightly change: First, immediately after introduction households have to sacrifice some of their herd growth in order to pay the insurance premium. This reduces grazing pressure on the pastures so they can accumulate more biomass. Therefore, pastures can sustain more animals during the next years (until the next drought hits in year 24). Additionally, during the drought, they use the insurance payout to maintain their herd size high. After the drought, herds have enough forage to grow, but, in the scenario with insurance, they have a head start relative to the scenario without insurance. Then the dynamics converges to a stable pattern in both cases: Without insurance, the typical boom-and-bust cycle emerges. Here, the drought reduces livestock numbers to the level at which it was at the beginning of the cycle. Yet with insurance, a different boom-and-bust cycle forms: Livestock accumulates immediately after the drought, but hits the carrying capacity of the remote patches. Therefore, pastoralists have to destock in the last two years leading up to the drought. Here, rainfall steadily declines towards the drought, so the amount of available grass also decreases. The insurance payout, however, is then used to reverse the previous destocking. A low grazing harshness (as shown in fig. 4) can buffer the additional grazing pressure. In our simulations, we define grazing harshness as the impact that grazing has on pasture growth. While a very low grazing harshness (gr_1 near 1) means that grass which is consumed by livestock does not have any impact on grazing dynamics, a very large grazing harshness (gr_1 near 0) means that only grass which is left over after grazing can contribute to biomass regrowth.

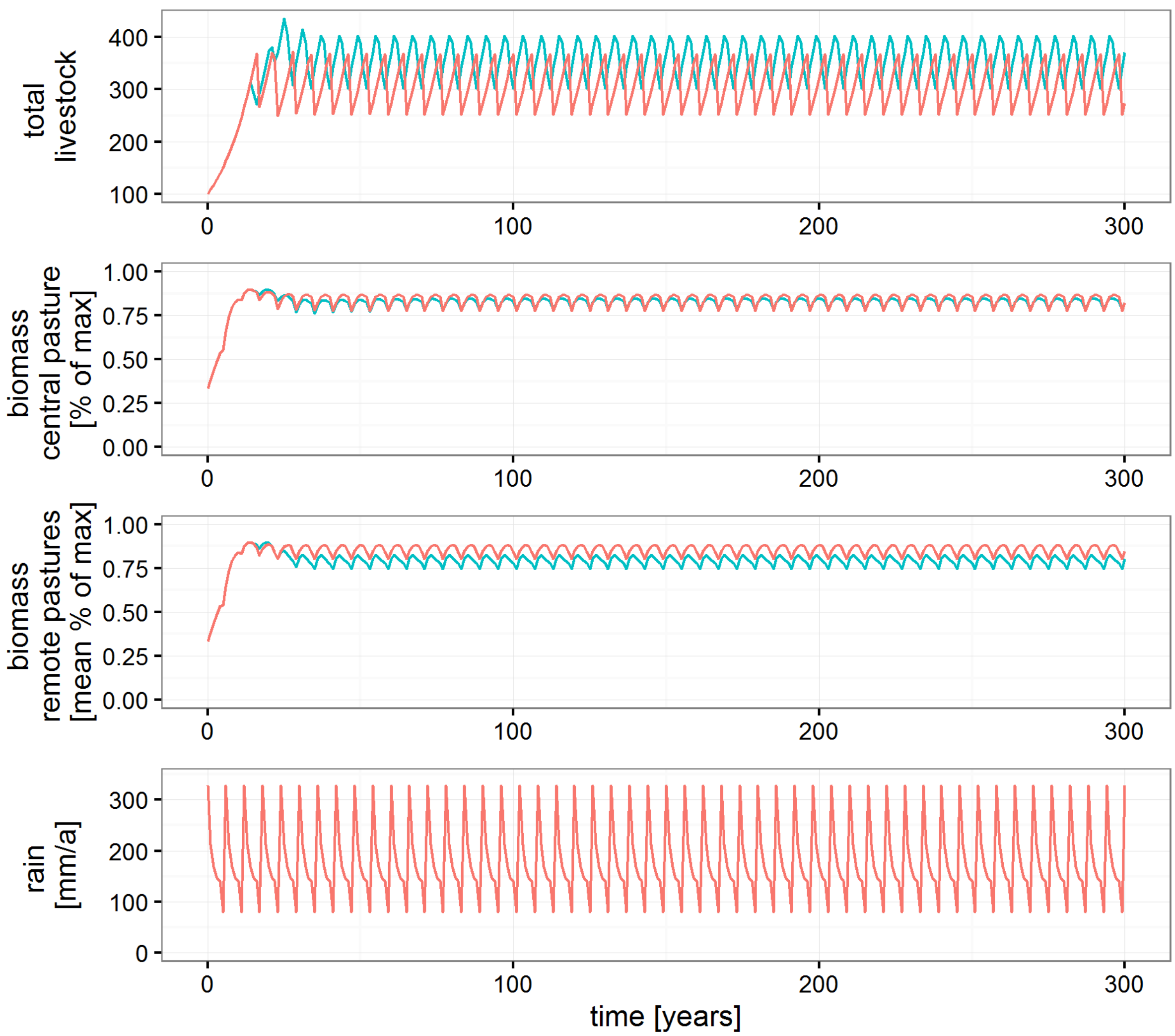

Fig. 4: Development of livestock numbers, biomass and rainfall over time with low grazing harshness (gr_1 = 0.75). Graphs depict the situation without (red) and with an insurance of up to 40 TLU (blue). Biomass values are normalized to the maximum reserve biomass.

If grazing harshness is larger, the dynamics can change (fig. 5). Again, the red graph depicts the simulation without insurance. Here, the pattern is less regular. It is visible, however, that the boom-and-bust cycle establishes over a period of two droughts, because livestock numbers break down so heavily during one drought that enough biomass can accumulate thereafter to buffer the effects of the next one.

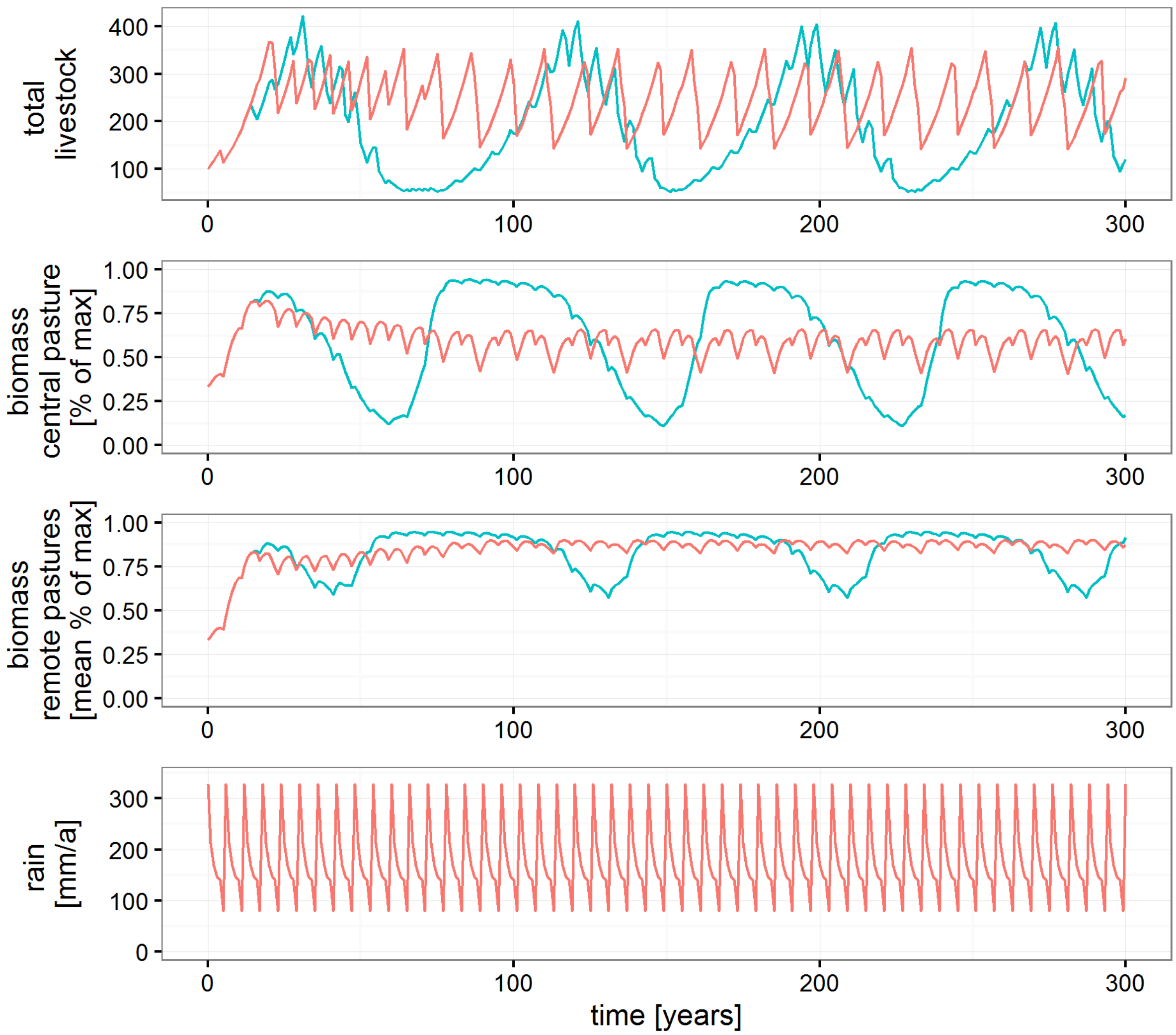

Fig. 5: Development of livestock numbers, biomass and rainfall over time with high grazing harshness (gr_1 = 0.1). Graphs depict the situation without (red) and with an insurance of up to 40 TLU (blue). Biomass values are normalized to the maximum reserve biomass.

Introducing insurance under these conditions turns the stable system into an oscillating one. Immediate restocking after the drought exerts a high pressure on pastures that leads to gradual degradation. The two middle panels of fig. 5 show that biomass cannot really recover after a drought. While the remote grazing areas can recover after a couple of droughts, wet season grazing areas near the village take considerably longer. Only at very low herd sizes (5 animals per herd) do the dynamics turn round and pasture recover. Yet the system cannot stabilise at the level of the no-insurance run. Instead, it overshoots and immediately enters in the next degradation phase.

Exploration of parameter space

We now present the long-term effects of differing insurance sums as well as varying levels of grazing harshness. We chose these factors to test the effects of insurance in different ecological and economic conditions.

As explained above, grazing harshness can be regarded to represent different kinds of ecosystems. Thus, a low grazing harshness resembles a rangeland with exuberant vegetation where grazing has hardly any effect on vegetation growth, whereas a high grazing harshness depicts a barren landscape with a high impact of grazing on vegetation growth.

On the other hand, the insurance sum is the main decision criterion that policy holders have. Insuring more animals, or even the entire herd, entails high yearly premium payments, but also ensures that all potential livestock losses are covered no matter how severe the drought. More risk-tolerant herders may insure only parts of their herd in order to reduce premiums, potentially assuming that not all their animals will be lost in the same drought.

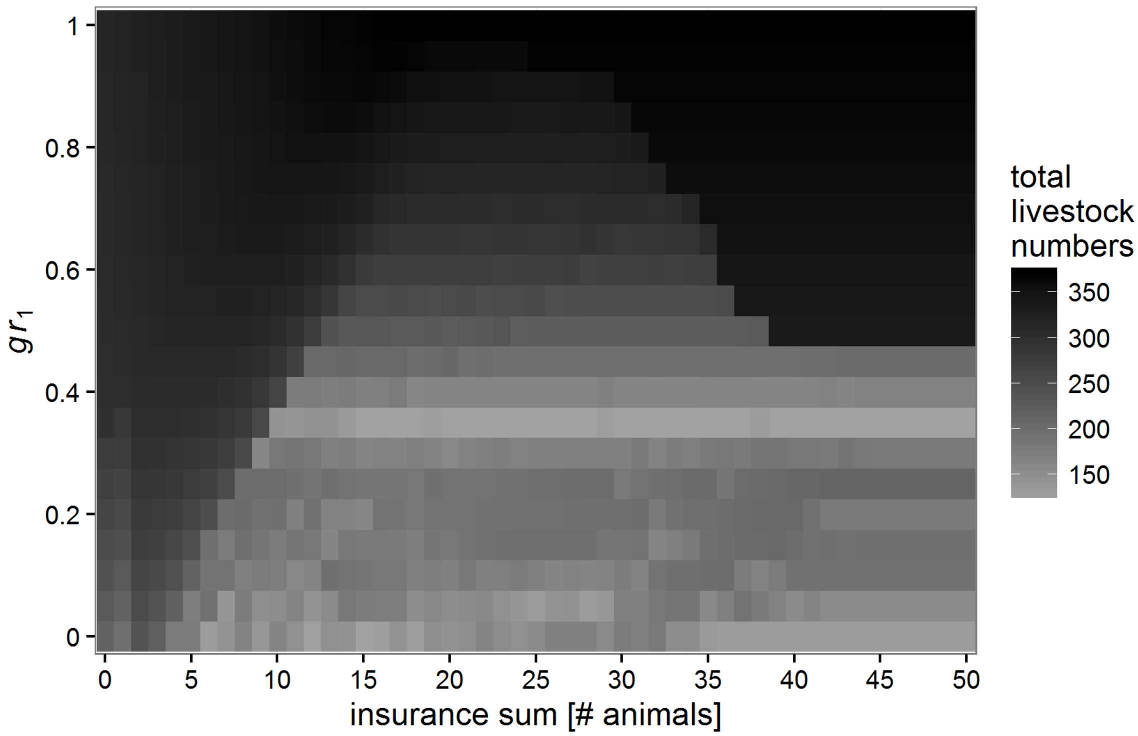

Fig. 6: Mean livestock numbers over time for descending rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

Fig. 6 shows long-term means of total livestock numbers for different degrees of grazing harshness and varying insurance sums. Grazing harshness describes the regeneration capacity of reserve biomass under grazing. In our model, gr_1 determines the contribution of consumed green biomass to reserve biomass build-up. Thus, a high gr_1 means a low grazing harshness and vice versa. A darker shade of grey indicates a higher long-term mean of livestock numbers. One general trend is that a lower grazing harshness (i.e. going up on y-axis) can support more animals in the long run. The effect of insurance, however, differs greatly. For low insurance sums, the payout after a drought is not high enough to substantially increase pressure on the pastures. Therefore, it can have a slightly positive effect on livestock numbers. If grazing harshness is high, a higher insurance sum turns the system from stable to oscillating (fig. 7). The resulting near-collapses reduce the long-term mean compared to not having insurance.

Lowering grazing harshness (i.e. going up on y-axis) can also decrease mean livestock numbers. When grazing harshness is barely high enough to avoid long-term oscillations of collapse and recovery (grazing harshness of 0.35 in figs. 6 and 7), livestock numbers stabilise at a relatively low level (long-term means are higher with oscillations due to the peaks during the short recovery phases). When insurance sum is sufficiently high (about 10 animals), restocking increases pressure on pastures such that less livestock is supported in the long run, but not as much as to cause oscillations.

For low grazing harshness ($gr_1 > 0.7$), the effect of insurance is mixed. Even though long-term degradation does not occur for any insurance level, two contrary effects can be observed: For low insurance sums, payouts can cushion the effects of a drought without compromising pasture regeneration, thereby allowing higher livestock numbers. Large insurance sums, on the other hand, entail high premiums which can often only be paid through destocking. This reduces grazing pressure and allows pastures to regenerate as well.

Interestingly, downside risk and long-term means show very similar results (fig. 8). Whenever only a small number of animals can be sustained, this also increases the risk to be worse off by purchasing insurance.

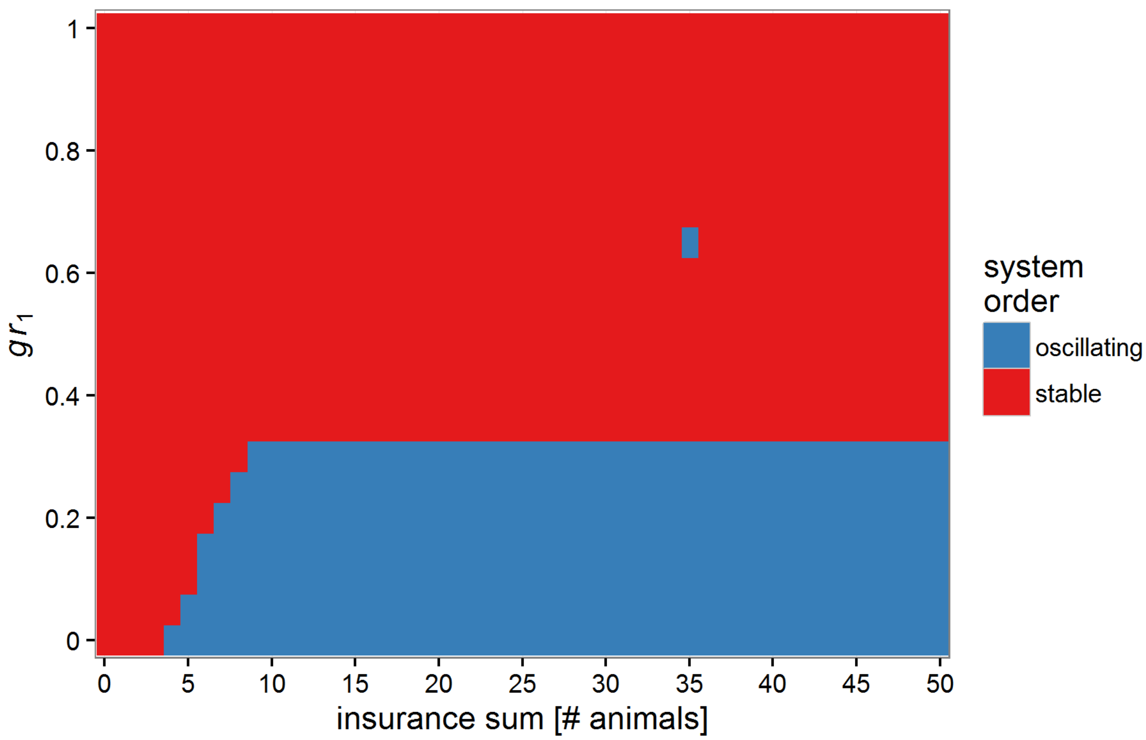

Fig. 7: Impact of insurance on system dynamics for descending rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

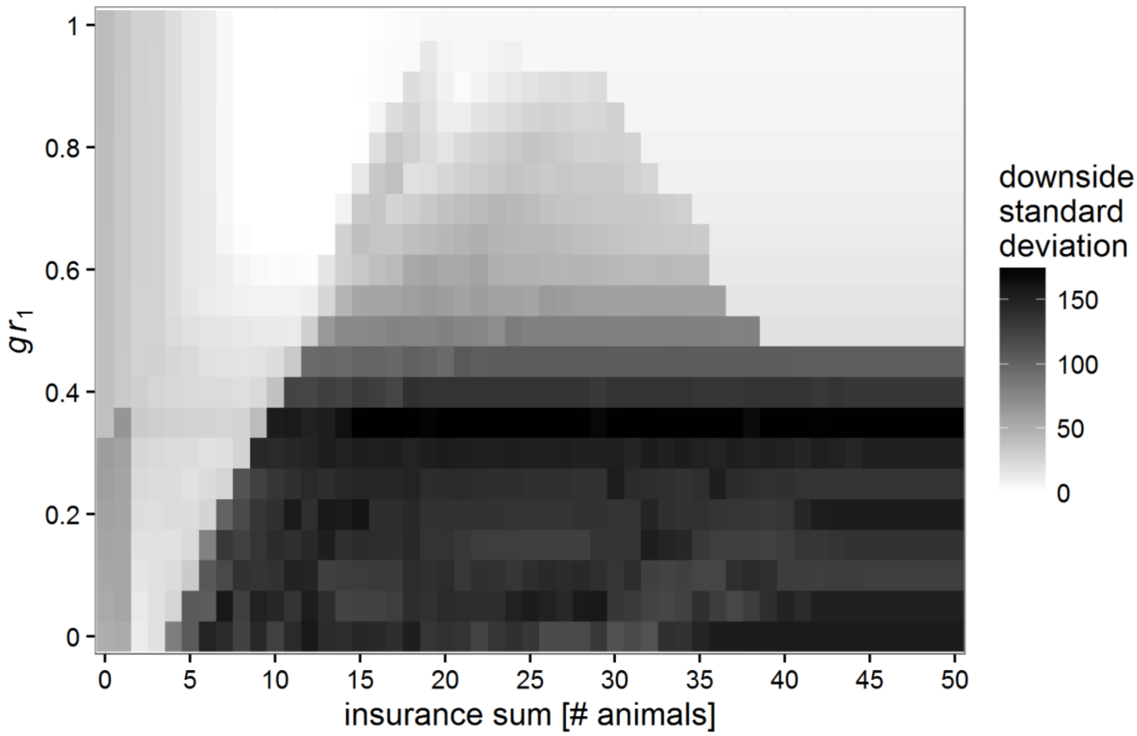

Fig. 8: Downside risk of falling below the livestock mean of the simulation without insurance for descending rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

Effect of insurance for different rainfall patterns

We then did the same analyses for different rainfall patterns and found similar effects. As already explained above, we took the most extreme scenarios with the highest negative and positive temporal autocorrelation. High negative autocorrelation results in an alternating pattern of high and low rainfall years (fig. 3 above); whereas the highest positive autocorrelation is achieved by bringing the values in descending or ascending order. So far, we presented results for a descending rainfall scenario (i.e. rainfall values are ordered from highest to lowest, starting again with the highest after a drought). Here, the very wet years after the drought contribute to a quick recovery of biomass and maybe even the build-up of a buffering capacity.

For negatively autocorrelated values, this effect is largely absent (fig. 9). The most prominent feature is that for a grazing harshness greater than 0.3, insurance does not seem to have any effect on neither livestock numbers nor system order. For lower grazing harshness, effects seem erratic. Long-term oscillations occur in almost all cases, sometimes they even lead to a total collapse, i.e. herders lose all their animals (fig. 10).

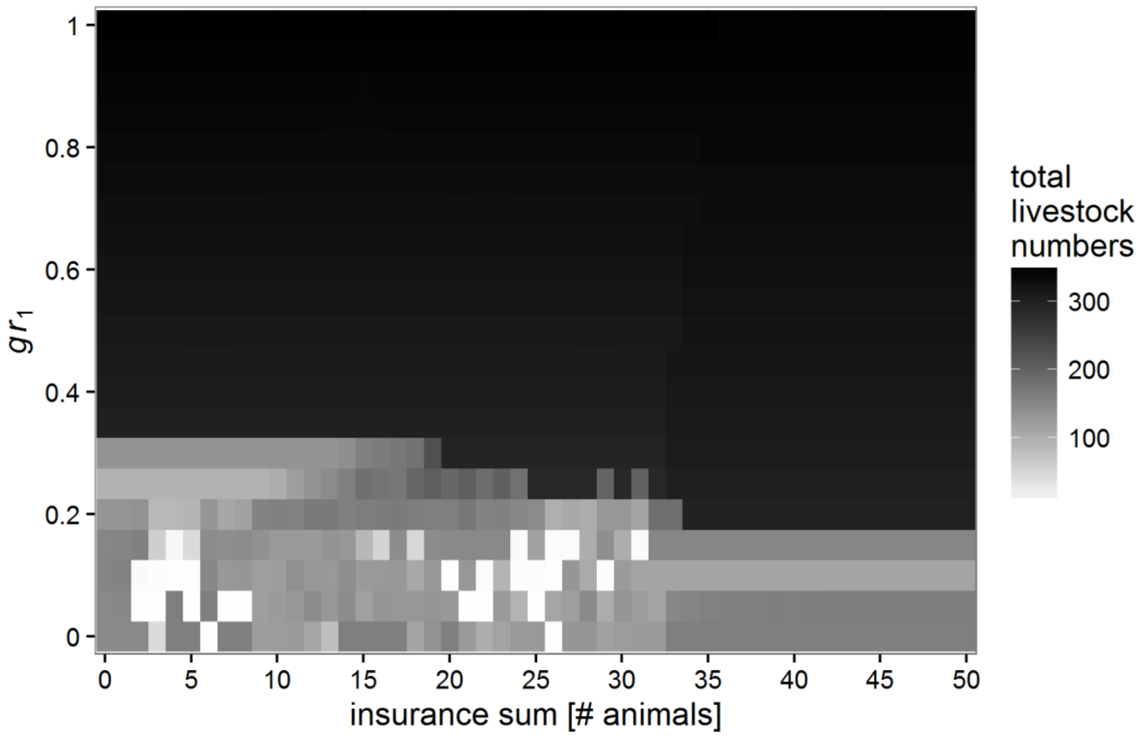

Fig. 9: Mean livestock numbers over time for alternating rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

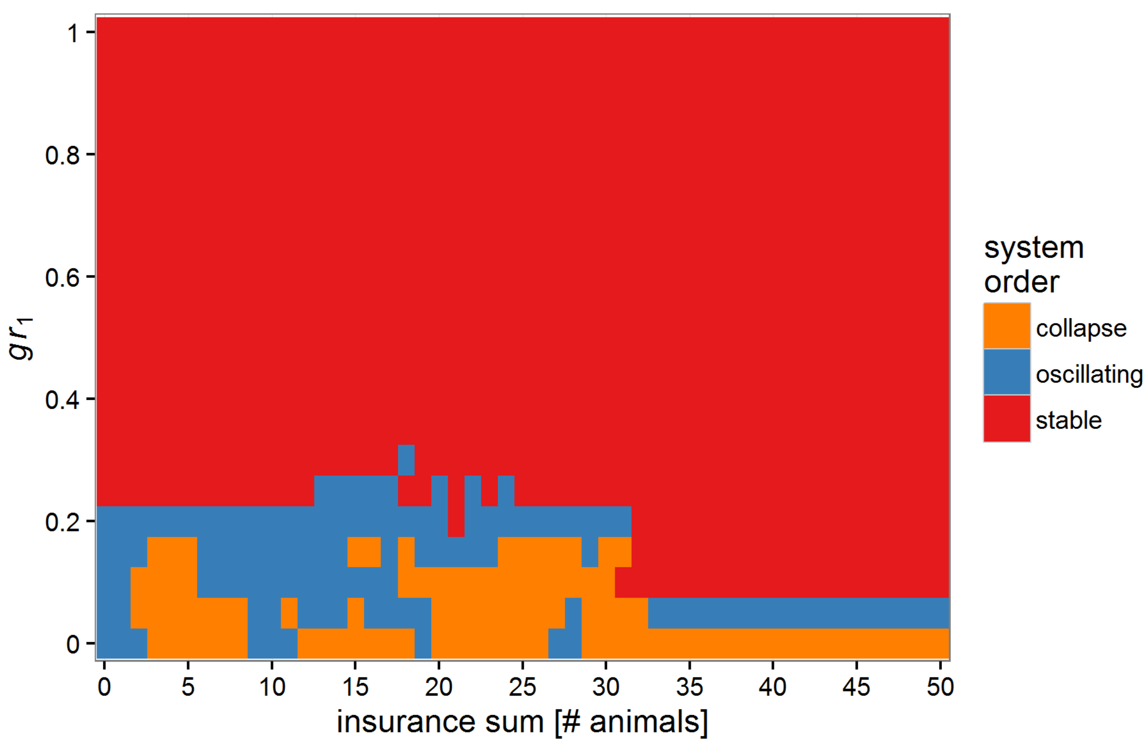

Fig. 10: Impact of insurance on system dynamics for alternating rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

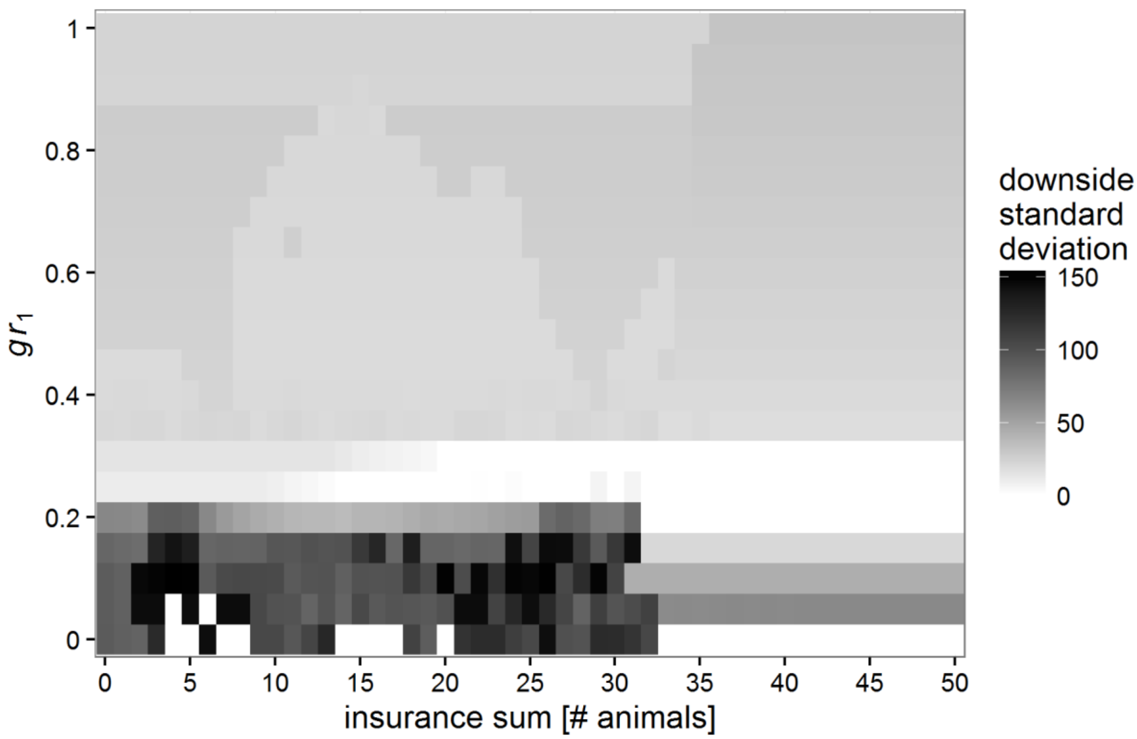

Fig. 11: Downside risk of falling below the livestock mean of the simulation without insurance for alternating rainfall dependent on the grazing harshness and insurance sum. Data generated based on a single run.

The results for ascending rainfall are not shown here, because they are qualitatively very similar to the ones with alternating rainfall.

4. *Discussion*

Our results show that insurance can both stabilize and destabilize the common property pastoral system, depending on the interplay of ecological and economic factors. Insurance can prevent hunger and poverty by cushioning shocks, but it can also leave pastoralists worse off by potentially causing long-term degradation.

Without insurance, drought reduces livestock numbers, which slowly recover in subsequent years and boom-and-bust cycles emerge. Insurance mitigates livestock losses caused by drought, which leads to higher stocking rates immediately thereafter. If pastures can recover sufficiently fast, they may sustain higher livestock numbers also in the long-run. If, however, pastures cannot handle the high post-drought grazing pressure, unsustainable overgrazing may occur from which a slow but steady degradation may originate.

The impact of insurance is often only regarded in economic terms and at the level of the individual beneficiary. In dynamic resource-use contexts, however, insurance has indirect effects as well that materialize in the interplay of different land users and their environment. So the impact of insurance can framed as a trade-off between the individual preference to avoid negative shocks and a community-wide interest to manage pastures sustainably. Insurance is a means to achieve the former, but at the expense of ecological buffering capacity. It is possible that, empirically, this systemic feedback effect will manifest only if insurance is taken up at a large scale. Nevertheless, it should be considered, since consequences can be substantial. This call for caution is all the more justified as our simulation results show that unintended ecological consequence unfold gradually and may not be detected at once.

It becomes clear that insurance does have an impact beyond the individual beneficiary, at least when taken up at scale. Other studies have found effects of insurance that could also bring about unintended consequences. Studies with Indian farmers showed that those farmers who have insurance take on higher-risk, higher-return investments (Mobarak and Rosenzweig 2013, Cole et al. 2016). While this may be beneficial to the farmers, on average, it can be bad for the labourers who end up facing higher wage risks (but do not necessarily get the upside benefit of the higher returns). This could be called a “pecuniary unintended consequence” of insurance, whereas our findings represent a “socio-ecological unintended consequence”.

Interestingly, our results suggest that the risk of obtaining unintended consequences is highest under those conditions when insurance is needed the most, that is when grazing harshness is high. In these cases, droughts are more likely to cause livestock losses, since grazing reduces the ecological buffering capacity already in non-drought years. Accordingly, pastures need more time to recover. Forgoing pasture resting can thus lead to unintended consequences, as has already been shown by Müller et al. (2007). On the other hand, when grazing has little effect on biomass growth, pasture buffering capacity is high. Pastures are not damaged as much by droughts, and moreover, they will recover faster. Under these circumstances, expected livestock losses will be lower. Therefore, insurance is not only less necessary, but, if taken up, would also have smaller ecological consequences.

To find an optimal balance between the desired economic and unintended ecological effects a thorough assessment of pasture conditions would be needed. Unfortunately, it is not possible, or at least very costly, to pinpoint this optimal state. Therefore, a practical second-best solution could be to restrict the amount of animals that can be insured. This limit should be high enough to ensure that farmers do not get caught poverty traps, which develop around 5 tropical livestock units (TLU) (Lybbert et al. 2004, Toth 2015), but not as high as to cause substantial ecological damage. Interestingly, this is exactly what the Kenya Livestock Insurance Programme (KLIP) does. In 2015, the Kenyan Ministry of Agriculture, Livestock and Fisheries started to offer an IBLI-like insurance of 5 TLU to vulnerable pastoralists for free.

Furthermore, our results hold for both designs of IBLI (i.e. asset replacement and asset protection). In the model, herds are destocked in case of forage scarcity and then restocked after payouts have been made at the end of a yearly time step (corresponding to the end of the short dry season in March). While this resembles the asset replacement design, the argument is even stronger for asset protection. In this case, early payouts aim at maintaining original livestock numbers throughout the drought (e.g. by fodder supplementation), so that there would be no periods of reduced stocking. Consequently, the risk of over-grazing is also higher. This reasoning is backed up studies which show that supplementing fodder only during droughts to reduce destocking can have detrimental ecological effects (Müller et al. 2015, Schulze et al. 2016).

Unfortunately, our model also has a number of limitations which point to the need of further research: In general, we work with a rather abstract and generic model. Even though it is adapted from the Borana pastoralists, it differs in a various ways from reality: First, we assume artificial rainfall time series. While the six rainfall values that we use are realistic, repeating them over and over again in the same order is certainly not. We additionally assume a constant intra-rainfall distribution. So the yearly rainfall is proportionally assigned to the different seasons. This also entails that in case of a drought, both dry seasons have very little rainfall. Second, households are homogeneous both in their initial endowments and their characteristics. Since herd growth is deterministic, inter-herd variation remains very small throughout the simulation. Third, we consider space only implicitly. While it is important that we distinguish between different grazing areas, their distances do not matter. Third, grazing is restricted to the defined areas, whereas a settlement would also share grazing areas with other settlements nearby. During droughts pastoralists would usually also travel larger distances with their herds, so that there would be some migration into and out of our considered landscape. Fourth, we assume pastures to consist of only one generic perennial grass type whose nutritional value is uniform. Thus, we cannot include issues like bush encroachment, which is a major problem in the Borana region

(Solomon et al. 2007). Fifth, we do not address the question of who takes up insurance, which is hotly debated (e.g. Hazell and Hess 2010, Binswanger-Mkhize 2012). Instead, we assume that all households purchase insurance to analyse the effects on a larger scale. In reality, however, uptake rates are usually low. Lastly, model validation and parameter estimation is often difficult for this type of model, since a number of parameters that are needed in the model are not easy to observe in reality (e.g. rain-use efficiency, the conversion factor of rainfall into biomass growth, is hard to measure). Therefore, we rely on sensitivity analyses for these parameters and validate them only qualitatively.

5. *Conclusion*

In dynamic resource-use contexts like common property pastoralist communities, introducing weather index insurance at scale can have systemic impacts. Cushioning substantial individual losses may be desirable from the perspective of the beneficiary, but at the system level it can stimulate unsustainable resource over-use, such as overgrazing. These socio-ecological feedbacks have to be kept in mind when designing insurance products to avoid unintended consequences. However, the hypothesis which is developed on the basis of our simulation model should be tested in the field.

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