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Climate Change and Optimal Farming Strategies in Semi-Arid Southern Africa

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Abstract

Climate change is a fact. It may have stronger impacts in the tropics than in moderate climates. At least from a farmer's perspective declining annual precipitation and higher rainfall variability is a challenge for viable farming strategies in semi-arid regions such as most of Southern Africa. In Central Namibia cattle and game farmers face rangeland degradation. Above all, bush encroachment leads already to a severe loss of pastures' production potentials. A question is will this be accelerated. A local farming system with respect to both, the economic decision making and the responding ecological dynamics to natural pasture dynamics, was investigated with the use of an ecological-economic model. Hereby, innovative technologies like new bush control measures were considered. To predict agro-ecological responses and future farm developments, 3 different rainfall scenarios have been simulated. Within the simulations the rainfall is stochastically generated and appears as input factor. Main results of climate change are more extreme rainfall events. Therefore, our generated rainfall scenarios are based on a reduced mean precipitation (10%, 20% and 30%) and at the same time increased standard deviations (again 10%, 20% and 30%).

In the 10% rainfall scenario, the farm development does not significantly change as compared to an extrapolation of the current precipitation. In the 20% (and 30%) rainfall scenario, the picture changes drastically. Farmers would face less biomass production and higher risk as well as more uncertainty. This has an impact on optimal farming strategies. Due to increasing risk and decreasing productivity, investments in rangelands (sustainable farming techniques) decline. In particular, investments in bush control do not pay anymore. This is even true for an application of new technologies of bush control such as hot fires; although it is a rather "cheap" tool. As a consequence bush encroachment increases as future returns become uncertain. In fact, with a climate change beyond a reasonable ecological/economic threshold (>20% rainfall-scenario) the optimal farming strategy would rather be to extract "all natural assets" quickly. As further simulations have shown, actual faming strategies also depend on the degree of indebtedness, labour costs, interest rates etc.. All in all, profit-seeking farmers might amplify the natural impact of climate change. This would lead to a self-enforcing mechanism of degradation as being dependent on risk.

1. Introduction

1.1 Global Climate Change

Recorded global surface temperatures have shown a significant increase within the last 100 years. Moreover, it is very likely that 1990 to 2000 was the warmest decade in instrumental records (i.e. since 1861). In this regard, the Intergovernmental Panel on Climate Change (IPCC) stated in their report from 2001 that it is likely that the rate and duration of the warming of the 20th century is larger than any other time during the last 1000 years. However, temperature is only one thing.

Global climate change has also an impact on the global precipitation and its distribution. In general, one can state that the global precipitation has marginally increased as IPCC data has shown. However, this development appears to be neither spatially nor temporally uniform. In particular, in Southern Africa climate change has differently affected the local weather regime.

1.2 Climate Change and Southern Africa

At the same times as the world as a whole receives a marginally increased rainfall, Southern African weather statistics have shown declining rainfalls for the last 30 years. Additionally, the intensity of extreme events increased significantly over Southern Africa. In other words, the region faces drier periods and longer droughts accompanied by an increased variability. Southern Africa is highly vulnerable to climate change due to a sensitive weather regime; but also extremely well adopted through biodiversity. In this regard, a complete loss of the Succulent Karoo biome is possible. However, long-lasting and often occurring droughts have tremendous impacts on local agricultural production, and thereby on the entire national economies of the whole region.
In this study possible impacts of an anticipated climate change on local agro-ecological systems are investigated. In particular, the study focuses on how climate worsening affects the interaction of farmers and the natural resource, i.e. rangeland. This can be achieved by ecological –economic models. This category of models is capable to show interdependences, and model simulations can predict future developments. Furthermore, well designed ecological-economic models can contribute to an identification of suitable policy measure for buffering harsh developments.

2. Material and Methods

2.1 Description of the Study Area

For this case study commercial farmers in the Okahandja district in Namibia were interviewed in 2001. The main focus of these farms is cattle production. It generates approximate 80% of total farm income. A recent development is an increasing engagement of farms in game ranching and tourism. The game sector can be seen as a diversification strategy. Wildlife and tourism, and here in first place trophy hunting, provides nowadays an increasing share of total income of those farms endeavouring in it; it can reach up o 50%. The local production system is based on natural pastures which are locally called “velds”. An average commercial farm unit in the region is about 10000 ha and subdivided in several camps by fences for allowing a proper grazing management.
Livestock and game farmers in the study region face numerous and relevant challenges. The most prominent threat for commercial livestock production is land degradation processes. The vegetation of the corresponding semi-arid savannah is very sensible to an overuse. Thereby, in the first place, overuse results in bush encroachment and leads to a severe decline in local carrying capacities; but also desertification appears in the area. Furthermore farmers face regularly occurring droughts. This stands for a high risk of farming in the entire region. Additionally, most of the interviewed farmers reported a high indebtedness, owing to cost intensive bush control measures and drought related losses in recent years. Then, farmers stated problems as related to labour as urbanisation of rural farm workers lasts and a new labour law leads to disputes on minimum wages. It is difficult to calculate pensions and avoid land utilisation claims. Finally, commercial farmers feel political uncertainty due to an ongoing discussion on the future land reform process
Apparently, climate change is a topic for the interviewed farmers, expressed their concerns. To add, local farm data on recorded rainfall suggests a declining trend of annual precipitation as measured over the last 30 years. Even though this trend is statistically not significant; climate change is a fact, at least from a farmer’s perspective, having already an impact on farming decisions.

2.2 Ecological–Economic Model

Our focus within the sets of ecological-economic models is the dynamics of bush encroachment and its control. Nowadays it is widely accepted that, among other reason, that selective grazing as performed by livestock like cattle leads to bush encroachment. However, the actual underlying ecological dynamics are complex. In this regard, recent perceptions on the ecology of semi-arid rangelands as contributed by Westoby et al. (1989) and Rothauge (2000) serve as a starting point. These authors perceive the ecology of rangelands as a state-and-transition dynamic which replaces former perceptions of degradation as being of a continuous succession process. A rangeland is characterised by multiple, quite stable ecological states, though transitions between certain states, which are triggered by bundles of different events, can occur. For example, a degraded ecological state of a rangeland shows quite a lot of newly established bush seedlings; but it can only be transferred back to an average good range condition if specific events like hot bush fire, limited grazing, and a good rainfall year occur, notably, all together. Within a state-and-transition-sub module a quantified application for rangelands in central Namibia has been conducted. For this purpose, five states of range land quality (Joubert & Rothauge 2001) are presumed. Moreover, farmers keep livestock of different age groups in three classes of annual stocking rates. Finally, different options for bush control exist within the model. On option not yet used in praxis but included is controlled bush fire on the basis of hot fires. At the moment fires are forbidden.

For a representation of the state-and-transition dynamics several possible activities are bounded to a certain ecological state of rangeland and they demand therefore for land at a defined state. For a further understanding each activity has a transfer vector, indicating whether the utilised land remains in the same state or appears in another state in the next time period (a change as probability indicates a transition). Furthermore, the ecological sub-model distinguishes whether an activity can only be applied in a special rainfall year (e.g. controlled bush fires are only possible after exceptional good rainfall years providing a sufficient fuel biomass) or are general applicable.

This ecological core module is supplemented by several ecological functions. For instance, the most important ecological function is the biomass production function. The amount of palatable biomass, produced per hectare, depends (1) on the current rainfall and (2) on the ecological state of a particular hectare. For this substantial function the necessary coefficients are derived from a five year data set from Agricultural College Neudamm (Rothauge 2002). In the ecological-economic model, annual precipitation is the most prominent exogenous factor. The rainfall appears stochastically following a normal distribution:

$RAIN_t$ = normal (µ, s)	with:
	µ: expected value
e.g. variable for simulation	s : standard deviation
	RAIN: annual precipitation
	t: time unit (years)

For investigating possible impacts of climate change four scenarios are simulated. In the base run scenario µ and s are based on average figures from local statistical data of the last 30 years. As indicated before, climate change in Southern Africa leads to drier periods and more extreme climate events. Consequently climate change for the case study region can be simulated by a reduced µ which is accompanied by an increased s . For this study a 10% scenario (µ -10%, s +10%), a 20% scenario (µ -20%, s +20%), and a 30% scenario (µ -30%, s +30%) are simulated.

For an **economic representation** all farm activities appear in a LP-structure, which is the basic farm modelling tool. Activities are, as already indicated besides bush control measures, cattle and wildlife activities (e.g. sell, keep, purchase, harvest etc.). They are dynamic and include finance planning. Furthermore, farmers have the option to hire additional labour. All these activities demand for scarce resources like biomass or labour and dynamics prevail. Within this structure, the contribution of specific activities to achieve farm income as objective (i.e. in this model: contribution to farm income) is defined as a multi-period goal. Furthermore intertemporal relationships are accommodated through transfer activities (see McCarl and Spreen (1997)).

In economic modelling an important component is the objective function. There, all farming goals find their ranked representation. In this study profit maximisation is assumed to be the objective of farmers. A dynamic optimisation considers time preference explicitly; it suggests a simple objective where farmers maximise the present value of future revenues. As these future revenues are derived from the natural resource, rangeland, the dynamic optimisation problem is based upon theoretical considerations for an optimal use of a renewable resource, as founded by Clark (1990). The time preference, itself, determines how strong farmers favour present incomes over future incomes; expectations are reflected by a discount rate within the objective function:

$$\max\ PV = \sum_{t=1}^{n} r_t (1+i)^{-t}$$

with:
PV: present value
r_t: revenue in the year t
i: discount rate
n: number of years (time horizon)
t: year

As the model deals with a planning horizon of 30 years, it needs to be stated what will happen to all remaining assets beyond the planning horizon. This aspect is accommodated in a transversality condition (see Lentz (1993) for a technical explanation). Labour costs and exogenous prices, for example of beef, trophies etc., are considered stable within respective economic model components. A more detailed model description as well as an extended discussion of the impact of time preferences on optimal farming strategies can be found in Buß and Nuppenau (2002).

3. Results

Figure 1 shows the generated rainfall scenarios for the next 30 years. The two curves (rain based on average rainfall data of the last 30 years and a generated rainfall based on the above described 30% scenario) show quite similar successions. This is essential for a comparison of the scenarios. A similarity of successions is achieved by a special random technique following processor time units (i.e. SEED command within GAMS). However, the importance of the 30% scenario is that it shows potential impacts of future climate change. In general, the new rainfall curve in Fig. 1 follows the extrapolated current rainfall curve, only a little reduction in level occurs. Notice, the rainfall peaks are of special interest. In this regard, drastic differences appear. For example, in the year 2025 the average base run predicts already a very dry years with an annual precipitation below 200 mm, but in the 30%-scenario the model predicts one year with almost no rain. Again, as commonly anticipated for a future climate change in Southern Africa, the model shows definitely higher rainfall variability. This presumably has the greatest influence on the agro-ecological systems.

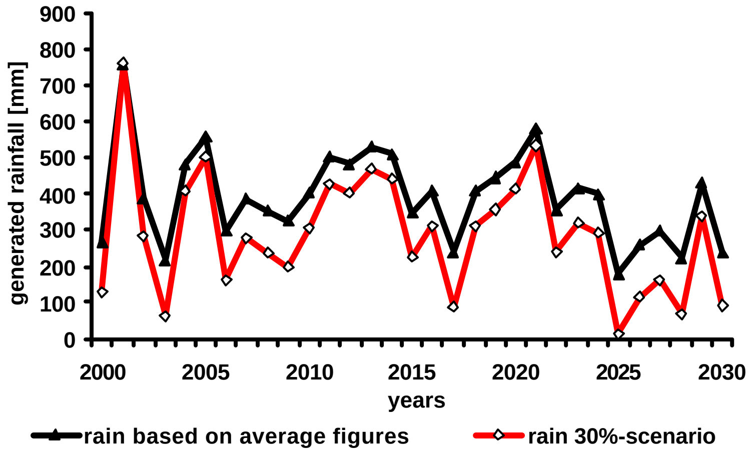

Fig. 1: Generated Rainfall-Scenarios for Central Namibia for 30 years

After verifying whether the model produces realistic rainfall scenarios, Fig. 2 gives some insights on how a changing weather regime affects specific decisions in rangeland management.

As bush encroachment is the most prominent threat for viable farming in central Namibia, investments in bush control measures on a 10000 ha farm indicate whether conducted farming strategies can be sustained in the long term. In the rainfall scenario based on average rainfall (black) the figure shows substantial efforts in bush control, undertaken through a continuous investment in the veld quality. Under the assumed influence of future climate change, notably in the 20%-rainfall scenario, the picture looks drastically different. Still, it is optimal for the farmer to invest in bush control, but to a much smaller extend. This smaller control inclination is not sufficient to support similarly high cattle numbers at a constant ecological state of the rangeland which would be given by the current climate conditions. Additionally, a significant difference between the scenarios would occur in terms of expenses. Bush control options are highly effective if they are composed of an individual treatment of bushes and herbicide granulates. The 20%-scenario shows deep cuts in investments in this effective bush control method. The cuts cannot be compensated by an increased prevalence of rarely applicable controlled bush fires. Consequently, despite some efforts in bush control, growing land degradation takes already place in the 20%-scenario.

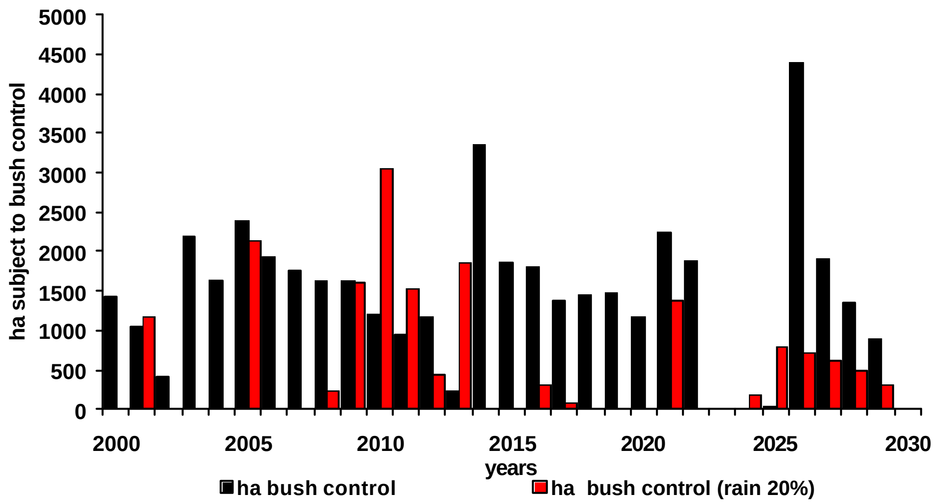

Fig. 2: Simulated Climate Change and Bush *Control of a 10000ha Farm in Central Namibia*

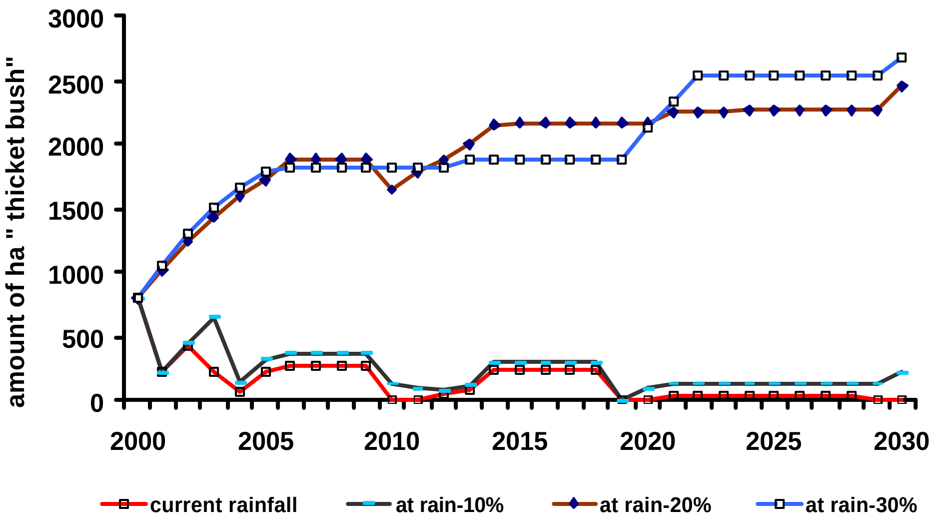

Fig. 3: Simulated Climate Change and Farm Development of a 10000ha Farm in Central Namibia

Fig. 3 illustrates the farm development with respect to degradation over the time horizon of 30 years for all four rainfall scenarios. The curves demonstrate the share of total hectares on a 10000ha farm being in a totally degraded state. In this state no more faming is possible especially due to high bush density. Under the current rainfall conditions it appears to be optimal to prevent land degradation on the entire farm for the planning horizon. As the amount of hectares covered by thicket bush tend to be zero after 20 years, it seems to be even favourable to revert already infected areas. This picture does not change too much for the 10% scenario. Still, it is an optimal farming strategy to keep the farm in a good state and to degrade only marginally in small areas.

In contrast, the impression alters severely for the 20%-scenario. Now it becomes an optimal farming strategy to utilise the rangeland without conducting sufficient efforts to maintain a good veld quality. It is optimal to degrade more than 20% of the entire farm within a short period of ten years. Again, the curve of the 20% climate change reflects both, the dynamically interacting natural environment and the economic decision-making of a profit-seeking farmer. For a farmer under the presumed basic condition of rainfall decline, a behaviour of increased degradation is optimal. This trend towards an "optimal" degradation strategy takes further place for the 30% scenario. At the end of the planning horizon more than 25% of the total farm drop out of production in that scenario. The model simulations indicate an ecological/economic threshold at the 20% rainfall-scenario. Notably, strategic changes in farm behaviour occur already at a comparably slight change in the rainfall regime. To generalise farmers' adoption to the changing environment can lead to an increase of bush encroachment for a whole region.

Faced with climate change, farmers will experience lower biomass productivity per ha as farms receive less average rainfall. However, the related biomass production curve for the 30%-scenario (within the first simulated years) shows only a marginal reduction of biomass production compared to current rainfall conditions. Only in extreme dry years, which take, noticeable place more often and more intense, the biomass production is much strongly reduced. This creates a big problem for sustaining herd. For farmers it becomes doubtful whether expensive investments in the rangeland quality and herds pay off in a higher productivity in future years, especially due to increased risks (i.e. higher rainfall variability). As a consequence, necessary investments in maintaining the resource basis will not occur and the land will experience degradation. Furthermore, starting after some years, also, the average biomass production will decline significantly in the medium term, particularly in extremely dry years; no food basis will be available. Finally, in the last 5 years of the planning horizon, the available biomass reaches merely less than 50% of the base line scenario. As climate change and man-made degradation work together the vegetation quality declines and reduces the biomass productivity of the land.

4. Conclusions and Discussion

Model results indicate that investments in natural resource rangelands and also sustainable farming techniques (i.e. lower stocking rates) get less attractive due to climate worsening. Furthermore, an ecological/economic threshold at the 20% rainfall-scenario has been identified through simulations. Beyond this threshold necessary investments in the veld quality to sustain veld productivity and thereby livestock production do not occur and degradation (i.e. resource extraction) becomes the superior farming strategy. The interaction of farmers and changing environment leads to an increasing bush encroachment. The result is that profit-seeking farmers amplify the natural impact of climate worsening in a given economic framework. This can be demonstrated without considering the additional increases in variability as based on intra-annual rain distribution analysis.

However, there is some scope for policy-makers to buffer the potential negative developments. As farmers are highly indebted, they show a high time preference. Other model simulations with a lower time preference (i.e. a lower discount rate in the model) show lower impacts. Mitigation can be achieved, for example, by cheap loans from land banks or a bush control subsidy. This will motivate farmers to improve the sustainability of their farming strategy and increase their investments in the veld quality (Buß & Nuppenau 2002). Another possibility, to combat the self-enforcing degradation process in case of climate change, would be to subsidise labour costs, as labour intensive bush control measures would become profitable (Buß & Nuppenau 2003), this would be an avenue. Furthermore, labour subsidies would provide the possibility for the Namibian government to combat the serious unemployment problem simultaneously. However, in the current political situation it remains doubtful whether these policies would be successful, as one has to admit the overwhelming effect of exceptional high time preferences of commercial farmers. In their decision-making, due to the political uncertainty related to the land reform process, time preference matters most.

Though, model predictions for a planning horizon of some decades are accompanied with uncertainties on coefficients, the results maybe robust. In general, in the long term, one would assume an adoption of new and better adapted technologies which are superior under the new climate regime. For instance, extensive small livestock production could become a viable farming option if the economic framework would adjust simultaneously. These adoptions would lead to a change of coefficients and also new price relationships, which appear fixed in the current simulation model, may alter the results. Finally, in a longer planning horizon of several decades (or even centuries), the vegetation will adapt to the new environmental conditions as well. Most probably, depending on the severity of future climate change and declining rainfall in Southern Africa, a shift towards a new biome will take place and thereby a complete change of the underlying vegetation dynamics is perhaps foreseeable. Obviously, the present model cannot predict the distant future without significant adjustments. This requests new research with a more flexible ecological background and interaction between economic and ecological research.

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