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Bush encroachment control and risk management in semi-arid rangelands

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ABSTRACT

We study the role of bush encroachment control for a farmer's income and income risk in a stochastic ecological-economic model of grazing management in semi-arid rangelands. In particular, we study debushing as an instrument of risk management that complements the choice of an adaptive grazing management strategy for that sake. We show that debushing, while being a good practice for increasing the mean pasture productivity and thus expected income, also increases the farmer's income risk. The optimal extent of debushing for a risk-averse farmer is thus determined from balancing the positive and negative consequences of debushing on intertemporal and stochastic farm income.

1. Introduction

Bush encroachment is considered to be one of the most extensive forms of degradation in rangelands in arid and semi-arid regions of the Earth (Sweet, 1998, de Klerk, 2004, Joubert et al., 2009, Schröter et al., 2011). With arid and semi-arid areas covering about one quarter of the land surface of the Earth, between 50 and 80% of these areas being used as rangelands, and more than one billion people earning their livelihood directly from livestock farming in these areas (Millennium Ecosystem Assessment, 2005), bush encroachment is a major worldwide problem. In Namibia, for example, where the economic well-being of more than two thirds of the population depends directly or indirectly on agriculture and some 70% of the national agricultural output is produced on commercial rangelands (Mendelssohn et al., 2003, MAWF, 2009), bush encroachment severely restricts profitability of cattle farming (Espach, 2006); the same goes for South Africa (Stuart-Hill, 1987, Börner et al., 2007) or Uganda (Mugasi et al., 2000).

From an ecological-economic point of view, rangelands in (semi-)arid regions are savannahs that are characterized by dynamic interaction and coexistence of woody and herbaceous vegetation, i.e. bushes and grass, under the influence of stochastic precipitation and bushfire, and that are managed for the purpose of livestock grazing (Knoop and Walker, 1985, Perrings and Walker, 1997, Wiegand and Jeltsch, 2000, Anderies et al., 2002, Beukes et al., 2002, Sullivan and Rohde, 2002, Janssen et al., 2004, Riginos, 2009). The crucial ecosystem service that limits livestock production and shapes farming strategies, is production of green grass biomass, which serves as a forage for livestock and thus generates farm income.

Low and highly variable precipitation, which is typical in (semi-) arid regions, causes a considerable income risk for farmers. The challenge of rangeland management is to optimally adapt to this highly variable and highly uncertain rainfall, taking into account ecosystem dynamics. Various grazing management strategies have been developed for that sake (Westoby et al., 1989, Behnke et al., 1993, Scoones, 1994, Heady, 1999, Rothauge, 2007, Hein and

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Weikard, 2008, Weikard and Hein, 2011). One such strategy, which is applied in many good-practice farms in Southern Africa, is to leave a fixed part of the pasture ungrazed in years with abundant rainfall ("resting in rainy years"), i.e. stocking is less than the grazing capacity of the pasture in such a year, while the pasture is used fully in years with low precipitation. Such conservative grazing management has been shown to be an efficient strategy for income risk reduction (Müller et al., 2007, 2011, Quaas et al., 2007, Quaas and Baumgärtner, 2012).

Ill-adapted grazing management strategies, including overstocking and suppression of bushfires, are the major anthropogenic causes of bush encroachment, i.e. the persisting occurrence of an ecosystem state dominated by woody vegetation (Roques et al., 2001, de Klerk, 2004, Joubert et al., 2008).[1] Bush encroachment leads to a reduction in the production of green grass biomass and, thus, to a reduction of grazing capacity of the rangeland (Sweet, 1998, de Klerk, 2004, Espach, 2006). As a consequence, farm income is diminished.

Bush encroachment control aims at increasing the long-term carrying capacity of the pasture through physical, chemical or biological eradication of excessive woody biomass ("debushing").[2] Generally, as in a savannah system there are not only negative but also some positive bush–grass interactions (Knoop and Walker, 1985, Smit, 2005), there is an optimal density of bushes that makes for the maximum carrying capacity of the rangeland (de Klerk, 2004).[3] Hence, debushing does not aim at complete eradication of woody biomass, but at reduction of bush density down to the optimal level. As a result of debushing down to this optimal level, grass biomass production increases significantly in the first year (Wölbling, 2008). Yet, bush encroachment sets in again after three to five years and grass biomass production drops. If a second round of complete debushing is then applied after some ten years, the effect of debushing persists for some twenty years (Wölbling, 2008, Krüger and Lubbe, 2010).

While the expectation is that, at bottom line, debushing increases a farmer's income, the exact effect of debushing on the intertemporal stream of farm income and, in particular, on the variability of income, has not been studied so far. In this paper, we study the role of debushing for a farmer's income and income risk in a stochastic ecological-economic model of grazing management in semi-arid rangelands. In particular, we study debushing as an instrument of risk management that complements the choice of an adaptive grazing management strategy for that sake.

We show that debushing, while being a good practice for increasing the mean pasture productivity and thus expected income, also increases the farmer's income risk. The optimal extent of debushing for a risk-averse farmer is thus determined from balancing the positive and negative consequences of debushing on intertemporal and stochastic farm income.

The paper is organized as follows. In Section 2, we present the stochastic and dynamic ecological-economic model, incorporating grazing management and debushing strategies. Section 3 describes the concepts and tools applied in the model evaluation. Section 4 presents the results of the study. Section 5 provides a discussion of these results and draws conclusions.

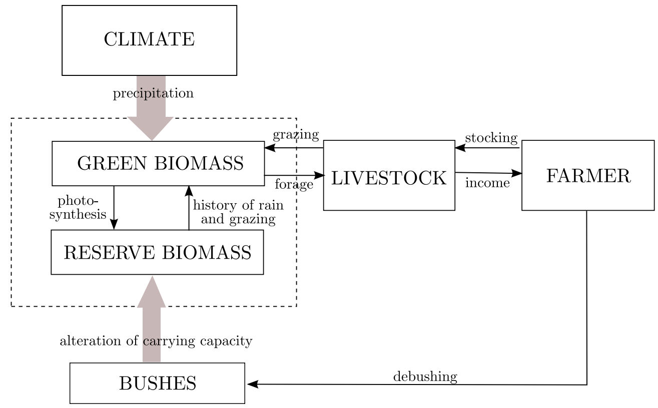

Fig. 1. Basic structure of the model.

2. Model

Our analysis is based on an integrated dynamic and stochastic ecological-economic model which is generic in that it captures essential and general principles of livestock grazing management in (semi-)arid regions. The basic model was developed in previous analyses of good-practice examples, in particular Karakul sheep farming in Namibia (Müller et al., 2007; Quaas et al., 2007; Baumgärtner and Quaas, 2009b; Müller et al., 2011). In this model, we include here a stylized description of debushing. The basic structure of the model is presented in Fig. 1.

2.1. Precipitation

The essential exogenous driver of vegetation and livestock dynamics in semi-arid regions, which introduces uncertainty into the system, is precipitation.[4] Precipitation is modeled as an independently and identically log-normally distributed random variable r (Sandford, 1982) with mean $\mathbb{E}[r]$ and standard deviation $Sd[r]$. The probability density function is

$$f(r) = \frac{1}{r\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln r - \mu)^2}{2\sigma^2} \right), \quad (1)$$

with $$\mu = \ln\mathbb{E}[r] - \frac{1}{2}\ln(1 + Sd[r])^2/\mathbb{E}[r]\Big) \quad (2)$$

$$\sigma^2 = \ln\left(1 + Sd[r]^2/\mathbb{E}[r]^2\right). \quad (3)$$

The distribution of rainfall events is right-skewed: events with low rainfall are frequent, but eventually high-rainfall-events occur. Precipitation is measured in units of effective rain events per year, that is the number of rain events that are effective in triggering

[1] Extreme droughts and climatic change are among the natural causes of bush encroachment, which seems to follow ecological cycles (Wiegand et al., 2005, Wiegand, 2010).

[2] Indirect management practices, such as decreasing the stocking rate of livestock in order to recover the grass cover require a much longer time than direct physical or chemical measures (Valone et al., 2002).

[3] For instance, for Namibia this optimal density of bushes can be estimated from the following rule of thumb (de Klerk, 2004: 60): two times the long-term average rainfall (measured in millimeters per year) in an area yields the optimal number of tree equivalents per hectare in that area, where a *tree equivalent* is defined as a tree (shrub) measuring 1.5 m in height (so that e.g. a 3-m shrub would represent 2 tree equivalents); for example, with a long-term average rainfall of 200 mm/a, some 400 tree equivalents per hectare would be optimal.

[4] We assume that bushfires are well controlled, i.e. suppressed, which is in fact the case in the system where our motivation comes from – commercial livestock farming in Namibia. Therefore, bushfires are not a source of additional stochasticity (besides precipitation) for green biomass production. This is in contrast to so-called "fire-driven" rangelands, where stochastic outbreaks of bushfire are an important driver of dynamics and endogenous fire management is an important part of any management strategy (e.g. Perrings and Walker, 1997; Anderies et al., 2002; Janssen et al., 2004).