Journal of Arid Environments 107 (2014) 49–56

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Prescribed fire as a tool for managing shrub encroachment in semi-arid savanna rangelands

Dirk Lohmann [a,*], Britta Tietjen [b], Niels Blaum [a], David Francois Joubert [c], Florian Jeltsch [a]

[a] Plant Ecology and Nature Conservation, Potsdam University, Maulbeerallee 2, 14469 Potsdam, Germany
[b] Biodiversity and Ecological Modelling, Institute of Biology, Freie Universität Berlin, Altensteinstr. 6, 14195 Berlin, Germany
[c] School of Natural Resource Management and Tourism, Polytechnic of Namibia, Private Bag, 13388 Windhoek, Namibia

ARTICLE INFO

Article history:
Received 11 February 2013
Received in revised form
6 February 2014
Accepted 9 April 2014
Available online 4 May 2014

Keywords:
Acacia mellifera
Bush encroachment
Dryland degradation
Rangeland management
Simulation model
Southern Africa

ABSTRACT

Savanna rangelands worldwide are threatened by shrub encroachment, i.e. the increase of woody plant species at the cost of perennial grasses, causing a strong decline in the productivity of domestic livestock production. Although recent studies indicate that fire might be of great importance for semi-arid and arid savanna dynamics, it is largely not applied in the management of semi-arid rangelands especially with regard to woody plant control. We used the eco-hydrological savanna model EcoHyD to simulate the effects of different fire management strategies on semi-arid savanna vegetation and to assess their long-term suitability for semi-arid rangeland management. Simulation results show that prescribed fires, timed to kill tree seedlings prevented shrub encroachment for a broad range of livestock densities while the possible maximum long-term cattle densities on the simulated semi-arid rangeland in Namibia increased by more than 30%. However, when grazing intensity was too high, fire management failed in preventing shrub encroachment.

Our findings indicate that with regard to fire management a clear distinction between mesic and more arid savannas is necessary: While the frequency of fires is of relevance for mesic savannas, we recommend a fire management focussing on the timing of fire for semi-arid and arid savannas.

1. Introduction

For decades shrub encroachment and changes in vegetation composition has been observed in savanna rangelands worldwide. Savannas originally dominated by perennial grasses with few scattered trees and shrubs have changed significantly into a state in which a few woody plant species encroach and dominate the plant community while perennial grasses almost disappear and less edible annual grasses as well as the overall fraction of bare soil increases (Buitenwerf et al., 2012; Fensham et al., 2005; Wigley et al., 2010). This so-called shrub or bush encroachment is often irreversible for several decades, and reduces the provision of fodder biomass for livestock production as well as other ecosystem services like water retention and protection from soil erosion (Gillson and Hoffman, 2007; Graz, 2008). Despite these negative implications, other studies also reported neutral or positive effects of an increase in woody vegetation cover for other ecosystem functions and services (see synthesis of Dahlberg, 2000; Eldridge et al. 2011). For example, Blaum et al. (2009a,b) showed a hum-shaped relationship between species richness of several animal taxa and shrub cover, with maximum species diversity at moderate levels of encroachment. However, very high levels of encroachment again lead to declining species richness and the authors found a species turnover along an encroachment gradient. Further, woody plant species are often perceived as important good (e.g. as firewood, for fence construction) by pastoralists on e.g. communal rangelands of southern Africa (Campbell et al., 1997), though encroaching plant species could be less desirable in this sense (Gordijn et al., 2012). Thus, careful management is required to avoid negative implications of shrub encroachment on a landscape scale but to also ensure the provision of positive effects of woody plants on a local scale. However, the prevailing conditions of high climatic variability, non-linear dynamics of shrub encroachment, and increasing pressure due to climatic changes and population growth pose a difficult task to local farmers and land managers (Gillson and Hoffman, 2007; Lohmann et al., 2012; UNCCD, 1994) and a universal explanation for the encroachment of savannas by woody plants has not been identified yet.

* Corresponding author. Tel.: +49 331 977 1959; fax: +49 331 977 1948.
E-mail addresses: dirklohmann@gmx.net (D. Lohmann), britta.tietjen@fu-berlin.de (B. Tietjen), blaum@uni-potsdam.de (N. Blaum), djoubert@polytechnic.edu.na (D.F. Joubert), jeltsch@uni-potsdam.de (F. Jeltsch).

http://dx.doi.org/10.1016/j.jaridenv.2014.04.003
0140-1963/

The interplay of several factors is generally assumed to cause shrub encroachment, including livestock (over-) grazing, the suppression of fires and an increasing level of atmospheric CO_2 (Tietjen and Jeltsch, 2007; Wigley et al., 2010). These factors can cause a shift in the competitive balance between the two major plant functional types, i.e. perennial grasses and woody vegetation (Graz, 2008). However, there is debate in literature as to what extent the different factors influence this competitive balance.

Clearly, grazing by domestic livestock is the process that is most often stressed to be responsible for shrub encroachment (Watkinson and Ormerod, 2001). The selective removal of grass biomass by cattle has the potential to release trees and shrubs from competition with grasses. Several studies found that especially seedlings of woody plants suffer from strong competition with perennial grasses and that grasses dominate competition for water in the topsoil (Kulmatiski et al., 2010; Ward and Esler, 2011). Further, Kambatuku et al. (2012) showed that water absorption by grass roots in the topsoil decreased deep infiltration: if grasses were clipped, more water was available in deeper layers of the soil and thus for shrub species with a deep rooting system. Consequently, the establishment success and growth of encroaching shrubs is greater when grasses are prone to intense livestock grazing (Kambatuku et al., 2011; Ward and Esler, 2011). However, grazing alone does not seem to be sufficient to explain shrub encroachment (e.g. Browning and Archer, 2011; Wigley et al., 2010).

Several studies, including modelling approaches address the issue of fire as a factor driving shrub encroachment in savannas (Higgins et al., 2000; Lehmann et al., 2014; Sankaran et al., 2005). However, literature on the effects of fire on savanna vegetation often does not distinguish mesic from (semi-)arid savannas. Studies from mesic savannas suggest that direct and indirect human interventions in natural fire regimes are essential drivers of the encroachment of shrubs in those savanna rangelands (Browning and Archer, 2011; Rohde and Hoffman, 2012). If the grass fuel biomass allows for frequent and hot fires, these are capable of controlling woody plant densities by destroying their aboveground biomass (topkill) (Bond and Keeley, 2005). Specifically for the demography of shrubs in mesic savannas fire plays a key role, since it potentially prevents saplings from growing to maturity and consequently from producing seeds (see Gulliver syndrome in Higgins et al., 2007a; Midgley et al., 2010). In contrast, studies from more arid savannas generally refer to low fuel loads that do not allow for fires hot enough to effectively kill adult shrubs as well as shrub saplings (Higgins et al., 2007a; Meyer et al., 2005). Therefore, fires are often assumed to be of little importance for controlling woody plant densities in arid and semi-arid savannas, although occurring frequently under natural conditions and affecting population structure (e.g. Buitenwerf et al., 2012; Higgins et al., 2007a; Liedloff and Cook, 2007). However, recent evidence from semi-arid and arid savannas shows that, although not leading to significant damage to adult shrubs and saplings, fire can severely impact the survival of young seedlings and thus the recruitment of tree species (Casillo et al., 2012; Harrington, 1991; Joubert et al., 2012; Taylor et al., 2012). In a recent review on the effects of fire and herbivory on savanna trees Midgley et al. (2010) suggest that young seedlings, which have a thin bark and only limited carbon storage, are likely to face high post-fire mortalities. This was confirmed by Joubert et al. (2012) and Casillo et al. (2012), who both tested the in-situ effect of fires on woody seedling recruitment in semi-arid savannas and found that tree recruitment is strongly inhibited by fires. Particularly seedlings of *Acacia mellifera* BENTH., which is one of the most important encroaching shrub species in semi-arid southern Africa, experienced post-fire mortalities of 97–99% after moderately hot fires (Joubert et al., 2012).

Encroaching woody species have been found to be strongly limited in recruitment by the highly variable water availability in semi-arid and arid savannas (Joubert et al., 2008; Kraaij and Ward, 2006), leading to mass recruitment events after a series of years with considerably above-average precipitation. Therefore, a fire event immediately after a year of mass germination might further narrow this recruitment bottleneck. Following this idea, fires should be of fundamental importance for the overall establishment success of woody vegetation in semi-arid savannas although grass biomass eventually does not exceed minimum thresholds for effective top killing of older tree individuals (compare with Trollope, 1984). Consequently, fire could provide a valuable tool for rangeland management, which has been largely unused so far (Harrington, 1991; Joubert et al., 2008; Midgley et al., 2010).

Yet, fire is seen critically by many land users, since it is potentially fraught with risks for infrastructure and livestock and, not least because scientific evidence regarding the role of fire on semi-arid savannas is controversial. Further, fire removes the desired biomass of grasses, which is the fodder for livestock production. Especially in semi-arid and arid regions, fires are thus often extinguished by land users or are prevented due to high levels of grazing and the respective lack of grass fuel biomass (Joubert et al., 2012; Scholes, 2009). For many regions fire suppression was linked to colonial expansion and the advent of European settler farmers, who mostly perceived fire as a problem (Rohde and Hoffman, 2012).

In this study, we assess the long-term effect of a fire-based management strategy for semi-arid and arid savanna rangelands that explicitly targets the demography of woody species encroachment, i.e. infrequent years of high seedling emergence. Under these conditions, which are characterised by prolonged (multi-season) periods of above average soil-water availability, semi-arid and arid savannas will also carry relatively high amounts of grass biomass and thus high fuel loads. This in turn favours intense fire event, which is capable of suppressing a mass recruitment of woody species (Harrington, 1991).

Based on the experimental evidence found by Joubert et al. (2012), we assess the long-term influence of systematic prescribed fires on the carrying capacity and degradation of a semi-arid savanna. For this, we use the savanna vegetation model Eco-HyD (Lohmann et al., 2012; Tietjen et al., 2010), which explicitly addresses specific demographic features of the typical encroacher plant *A. mellifera* and its competition with grasses. The eco-hydrological approach of the model assures that the important dynamics of soil–water availability are represented in sufficient detail and thus enable a realistic simulation of the water-triggered demographic bottleneck of the woody plant type. On this basis, we simulate the application of prescribed fires after woody species germination in combination with a broad range of grazing intensities. In particular we assess how such a controlled fire regime interacts with different grazing intensities especially with regard to (1) its efficiency in controlling woody plant encroachment and (2) its capability of increasing semi-arid savanna capacity for livestock production.

2. Methods

2.1. Study area

The model was parameterised to conditions of a typical semi-arid Namibian Acacia-tree-and-shrub savanna of the Central Kalahari type (Mendelsohn et al., 2002) as found at the governmental research station at Sandveld (latitude 22°02'S longitude 19°07'E). The study area, which has been a research farm since the late 1960s, was used for livestock production for about 80 years. The