Modelling the Rate and Pattern of Woody Thickening in Australian Savanna Pastures

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Abstract: The density of trees and shrubs is increasing (thickening) in many savanna pastures across northern Australia. These pastures are primarily used to produce cattle for live export. As pastures thicken with trees and shrubs, forage production and cattle outputs may decline. Field experiments and other studies are unravelling the causes of this thickening, which is related to a complex interaction between soil type, climate fluctuation, fire suppression, and grazing utilisation. These complex interactions are simulated by the SAVANNA model to predict the rate and spatial spread of woody regeneration on different soils across a paddock on Kidman Springs in the Victoria River District of northern Australia. First, increased thickening of woody regeneration was simulated for a historical climate sequence under a no fire, high grazing regime. Then, simulations were used to explore how this thickening might be reduced, or reversed, by using different combinations of fire and grazing. This full set of simulations, along with the field experiments used to validate SAVANNA, suggest the following general conclusions: (1) thickening of small woody plants (tree regeneration and shrubs) is rapid under a regime of no fires on red soils, with or without cattle grazing; (2) this woody thickening can be reversed with fires, although this reduction is less if pastures are grazed by cattle, which reduces fuels. A management principle for savanna pastures that emerges from these simulations is the critical importance of the balance between using pasture as forage for cattle or as fuel for fire to control woody thickening. In the future, these paddock scale simulations need to be expanded to the property scale where economic and social management principles apply.

Keywords: Models; Pastures; Rangelands; Savanna; Simulation; Tropics

1. INTRODUCTION

Savannas have been defined as having a continuous grass layer within a discontinuous tree layer [Scholes and Archer, 1997]. If the tree layer thickens in savannas used as pastures, then forage yield declines (Figure 1) [Scanlan and Burrows, 1990; Cafe et al., 1999] and cattle liveweight performance can also decline [Burrows et al., 1990]. If woody thickening leads to increased mustering costs and to reduced forage and cattle production, then economic and social hardships can be imposed on pastoralists in savanna regions [Landsberg et al., 1998; Rolfe et al., 2000].

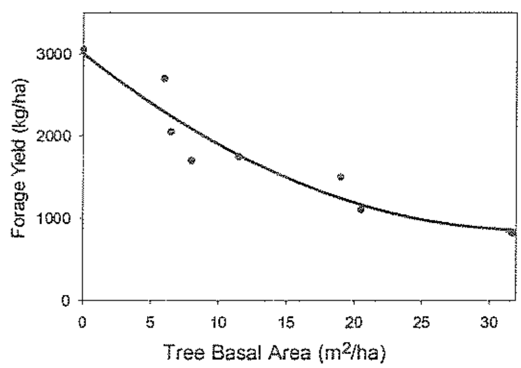

Figure 1. Forage yield versus tree basal area [data from Scanlan and Burrows, 1990].

Woody thickening in savannas has been attributed to a number of interacting factors including fire suppression, cattle grazing and extreme seasonal variability [Fensham, 1998; Dyer and Mott, 1999]. For example, the suppression of fire has caused a marked thickening of woody plants on many savanna pasturelands in the Victoria River District [Kraatz, 2000]. Fires can be suppressed by strategically placing fire-breaks and by actively fighting wildfires. In addition, fuels required to carry the fires needed to control woody plants can be reduced by cattle grazing, especially during droughts [Schulz, 1998]. There is a strong tradeoff between grazing and fire where fire frequency and intensity are reduced if fuels are consumed as forage by cattle [Liedloff et al., 2001].

Field experiments and measurements have been used to quantify some of the trade-offs between savanna tree density, forage availability, cattle gains and fire frequency [e.g., Ash et al., 1997; Dyer and Mott, 1999]. These data have also been used to parameterise and validate simulation models that can be used to explore trade-offs over a range of conditions that would be very difficult and costly to examine with field experiments. These modelling studies have focused on predicting changes in forage yields and cattle gains through time under different tree densities, fire regimes and climatic conditions [e.g., Cafe et al., 1999; Liedloff et al., 2001]. They have not been used to explore how the spatial spread and thickening of woody plants change forage and cattle production in a paddock.

In this study we used a spatially explicit savanna simulation model to predict changes in small woody plants (i.e. tree regeneration and shrubs) across a savanna paddock, and how different combinations of fire and grazing alter these changes (e.g., can woody thickening be stopped or reversed using certain trade-offs between fire and grazing regimes?).

2. THE MODEL, STUDY AREA AND DATA

A spatially explicit savanna simulation model, SAVANNA, was used in this study. This model was specifically developed to simulate the structure and function of savannas [Coughenour, 1992]. SAVANNA is composed of sub-models for soil water balance, plant production, herbivory and animal production. This model uses a weekly time-step and is driven by weather data.

The weather data used to run SAVANNA was obtained from the Victoria River Research Station located at Kidman Springs in the Victoria River District (VRD) of the Northern Territory (Figure 2). Average wet season rainfall (Oct.-Apr.) is 617 mm based on a 112-year record for nearby Victoria River Downs Station [Clewett et al., 1999]. Most of this wet-season rainfall occurs as high intensity storms. The field data used to parameterise and initialize SAVANNA included, for example, information from a fire experiment [Dyer et al., 1997] and a grazing gradient study [Ludwig et al., 1999] in Conkerberry Paddock on the Research Station. The Research Station at Kidman Springs has a mix of vegetation and soil types but is mostly wooded savanna on calcareous red loam soils and more open grassy savanna on grey cracking-clay soils.

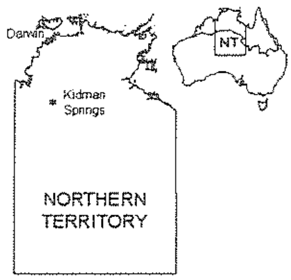

Figure 2. Location of the study area, Kidman Springs, Northern Territory, Australia.

3. SAVANNA SIMULATIONS

Simulation scenarios included were different combinations of fire and grazing, including no fire, low intensity fires every 5 years (low fire), high intensity fires every 10 years (high fire) with no grazing, low-levels of grazing (5 hd/km2) and high-levels of grazing (20 hd/km2). Whether fire intensity is low or high depends on fuel load and state of curing, site factors and weather conditions (Fensham, 1990; Gill et al., 1996; Williams et al., 1998).

Results from combinations of no, low and high fire and levels of grazing were tabulated; however for brevity we will only illustrate in a diagram three savanna management combinations: (1) no fires and no grazing, (2) no fires and high levels of grazing, and (3) high intensity, frequent fires with no grazing. The fourth combination of high fire and low or high grazing is not presented because it is an unlikely scenario – intense, frequent fires do not occur when paddocks are subject to high or low levels of grazing. These simulations were run for a 40-year record of climate data for Kidman Springs, which covered the period from 1957 to 1997.

A site within Conkerberry Paddock was simulated. This site included three vegetation-soil zones (Figure 3), including (1) wooded savanna, WS, on red loam soils, with a 10% canopy cover of *Eucalyptus terminalis* and *E. pruinosa* trees (>1.5m); (2) grassy savanna, GS, on grey clay soils with a 0.5% canopy cover of *Terminalia volucris* and *Lysiphyllum cunninghamii* trees; and (3) an ecotone zone, EZ, with intermediate canopy cover of these trees (5.0%) where red loam soils overlie grey clays.

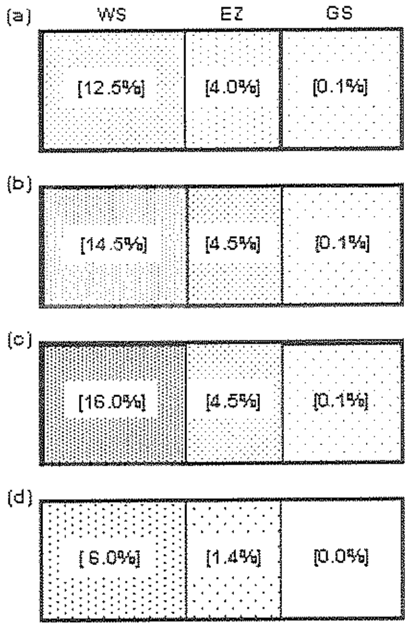

Figure 3. Illustration of small woody plant thickness (tree regeneration and shrub canopy cover as stippling) within three vegetation-soil zones: WS, wooded savanna; EZ, an ecotone zone; and GS, grassy savanna. Denser, darker stippling is higher cover and thinner, lighter stippling is lower cover, with canopy covers given in square brackets. Illustrated for these three zones are: (a) estimated initial canopy covers in 1957, and (b) predicted covers in 1997 (40 year simulations) given no fire or grazing, (c) no fire but high levels of grazing, and (d) high fire every 10 years and no cattle grazing.

We initialised SAVANNA runs by estimating that in 1957 the canopy covers of tree regeneration and shrubs (<1.5m) for these three vegetation-soil zones were 12.5% in wooded savanna (WS), 4.0% in the ecotone zone (EZ), and 0.1% in grassy savanna (GS) (Figure 3a). We based these estimates on historic descriptions and photographs for the Victoria River District [Kraatz, 2000], and fixed-point photos taken in Conkerberry Paddock in 1973 [Foran et al., 1985].

If this site within Conkerberry Paddock remained unburnt and ungrazed from 1957 to 1997, the SAVANNA simulation model predicted that the cover of tree regeneration and shrubs remained very low in grassy savanna but increased in wooded savanna and ecotone zones (Figure 3b). This predicted woody thickening was markedly greater in wooded savanna disturbed by cattle grazing at high levels (Figure 3c). Although not illustrated, similar changes occur under low-levels of cattle grazing (Table 1). These predictions are supported by observations and data collected from inside two unburnt and ungrazed exclosures and from outside these exclosures in Conkerberry Paddock [Bastin et al., 2000].

Table 1. Predicted canopy covers in 1997 for small woody plants (tree regeneration and shrubs <1.5m), and the amount of change from 1957 (in brackets), for different combinations of fire and grazing on three vegetation zones in Conkerberry Paddock, Kidman Springs: wooded savanna, WS; an ecotone zone, EZ; and grassy savanna, GS.

Scenario		Vegetation-Soil Zone		
Fire	Grazing	WS	EZ	GS
No	No	14.5% (+2.0)	4.5% (+0.5)	0.1% (0.0)
No	Low	15.0% (+2.5)	4.5% (+0.5)	0.1% (0.0)
No	High	16.0) (+3.5)	4.5% (+0.5)	0.1% (0.0)
Low	No	10.0% (-2.5)	2.0% (-2.0)	0.0% (-0.1)
Low	Low	11.2% (-1.3)	3.0% (-1.0)	0.0% (-0.1)
Low	High	11.0% (-1.5)	2.8% (-1.2)	0.0% (-0.1)
High	No	6.0% (-6.5)	1.4% (-2.6)	0.0% (-0.1)
High	Low	--*	--*	--*
High	High	--*	--*	--*

* Simulations were not run because a high fire is unlikely to occur in paddocks grazed at low or high levels

In contrast to these predictions of thickening with no fires, the SAVANNA simulation model predicted that if the site was ungrazed and burnt every 10 years (i.e. in 1967, 1977, and 1987) with high-intensity fires (high fire, no grazing treatment), then the cover of small woody plants is likely to decrease in all three vegetation zones (Figure 3d). This decrease or reduction in thickening relative to 1957 and compared to the 'no fire' scenarios, was also predicted for the low fire treatment, with changes likely to be greatest in the wooded savanna and ecotone zones (Table 1). With low or high fires at a frequency of 1 fire in every 5 or 10 years, respectively, the grassy savanna area is likely to remain clear of trees. These model findings are supported by fire and tree thinning experiments conducted in these vegetation communities in Conkerberry and nearby paddocks [Dyer et al., 1997; Cafe et al., 1999; Dyer and Mott, 1999].

4. MANAGEMENT IMPLICATIONS

Our SAVANNA model simulations for savannas on Kidman Springs suggest that with no fire or grazing woody thickening is likely to occur in wooded savanna and ecotone zones. These are the areas with calcareous red-loam soils and where these soils are forming a thin layer over grey cracking clays due to hillslope erosion processes [van Wieringen et al., 2001]. This woody thickening was not predicted by SAVANNA for grassy savannas on grey soils, although some of these areas have experienced thickening in the VRD [Bastin et al., 2000; Kraatz, 2000]. This thickening in grassy savannas may not be evident in our relatively short (40 y) simulation runs, perhaps because SAVANNA does not mimic exogenous woody seed 'rain'.

Our predictions for thickening in wooded savannas and in ecotone zones do not imply that in semi-arid, wet-dry tropical environments, wooded savannas would continue to thicken into forests. It is known that periodic severe droughts in semiarid savanna regions with 600-700 mm mean annual rainfall will cause tree 'die-back' (i.e., will naturally thin trees) [Fensham, 1998; Fensham and Holman, 1999].

This simulation, along with findings from field experiments on Kidman Springs [e.g., Dyer et al., 1997; Cafe et al., 1999] clearly implies that both low and high intensity fires can serve as effective tools for reducing woody thickening, provided fuels are adequate to carry these fires. The SAVANNA model predicts that with no grazing and with low-levels of grazing, sufficient fuels occur for managers to use low fires to control woody thickening at a frequency of one year in 5 years. This implies that wisely grazing paddocks or using strategic spelling (no grazing to build fuels) will provide the fuels needed to control thickening in savanna pastures while also providing economic returns from cattle.

However, the SAVANNA simulations presented here need to be viewed cautiously. This model requires further validation to build confidence in its predictions before exploring other management trade-offs for savannas across northern Australia.

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