Modelling the Trade-off between Fire and Grazing in a Tropical Savanna Landscape, Northern Australia

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Abstract As savannas are widespread across northern Australia and provide northern rangelands, the sustainable use of this landscape is crucial. Both fire and grazing are known to influence the tree-grass character of tropical savannas. Frequent fires open up the tree layer and change the ground layer from perennials to that dominated by annuals. Annual species in turn produce copious quantities of highly flammable fuel that perpetuates frequent, hot fires. Grazing reduces fuel loads because livestock consumes fuel-forage. This trade-off between fire and grazing was modelled using the spatially explicit, process-orientated model (SAVANNA) and field data from fire experiments performed in the Victoria River District of northern Australia. Results of simulating fire (over 40 years) with minimal or no grazing pressure revealed a reduction in the shrub and woody plants, a reduction in grasses, and no influence on the tree structure given mild fires. While mature trees were resistant to fire, immature trees, which are more likely associated with the shrub layer, were removed by fire. The overall tree density may be reduced with continual burning over longer time periods because of increasing susceptibility of old trees to fire, and the lack of recruitment. Increases in stocking rates created additional forage demands until the majority of the fuel load was consumed, thus effectively suppressing fire and reverting to the grazing and suppressed fire scenario where trees and shrubs established.

1. INTRODUCTION

The dominant vegetation type of northern Australia is the savanna. This habitat consists of a variable tree layer ranging from grasslands and low sparse shrublands to *Eucalyptus* woodlands, all with a continuous grass layer [Mott et al.1985].

Northern Australia is tropical and receives seasonal rainfall with the majority falling in the wet season (November-April). This season is followed by an equally consistent dry season where much of the wet season vegetative growth dies. This material produces fine, quick drying and well-aerated fuels for fire.

1.1 Fire

Extensive and frequent fires are a feature of northern Australian savannas. For example, most of Kakadu National Park burns every three years during the dry season [Russell-Smith et al. 1997]. This frequent occurrence of fire determines the structure of the savanna by influencing the tree-grass balance. In the absence of fire, woody vegetation increases both in the cover and height. Frequent burning will reduce or at least maintain the trees and shrubs. The majority of woody species are well adapted to fire with mortality rates below 5% [Williams et al. 1999]. Susceptibility to fire by these species decreases with age and is affected by fire intensity.

Several factors determine the type of fire and most importantly the intensity. The most critical is the season of burning. Fires burning in the early dry season tend to be of low intensity as fuel still has moisture from the wet season. These fires often burn patchy and, while removing litter and much of the grass layer, have little affect on the vegetation in the following season [Williams et al. 1999]. Late dry season fires are intense and often unpredictable due to the low moisture content of the vegetation, rising temperatures, low humidity and variable wind patterns. These fires often burn large areas and have the potential to modify the savanna due to the higher mortality of woody species.

As fire has the ability to modify or maintain the structure of the tropical savannas, it is often used as a management tool. This introduces a number of management implications, as different users of the tropical savannas frequently require different fire practices. Numerous reports suggest that the savannas have a greater number of woody species than reported in the past [Dyer and Mott 1999]. This has been attributed to the recent European practice of suppressing fire. For this reason fire is currently used to remove and manage woody species.

While much of the vegetation is able to cope with frequent, intensive fires, such fires may be responsible for the contraction of fire sensitive, non-savanna habitats such as monsoon vine forests [Russell-Smith et al. 1998].

1.2 Grazing

The majority of the tropical savannas are used as rangelands for cattle grazing [Mott et al. 1985]. Management of grazing properties requires that the best pasture conditions are maintained.

Burning of the tropical savannas leads to reduced woody material, the removal of some woody weeds, release of nutrients held in dead standing and therefore unpalatable material, and an increase in green pick [Russell-Smith et al. 1998]. These responses of the savanna to fire mean fire can be used as a management tool to improve and maintain quality pastures.

1.3 The Model

This study combined the results of comprehensive fire studies in the Victoria River District [Dyer et al. 1997](Figure 1) and Kakadu National Park [Williams et al. 1999] with the use of a simulation model to better understand the effects of fire and grazing on savannas. The model allowed a range of scenarios to be considered that would have been extremely costly or simply not feasible with field experiments alone.

The model, SAVANNA, was developed to simulate the structure and function of savannas and other grasslands, shrublands and woodlands [Coughenour, 1992]. This model is spatially explicit and process orientated and consists of a number of sub-models used to determine aspects such as plant population dynamics, plant biomass production, site hydrology, ungulate population processes and herbivory, nutrient uptake and cycling, and fire responses. The fire sub-model simulates the response to fire in terms of changes in plant density, size and biomass based on fire intensity.

The model was parameterised for Kidman Springs, Northern Territory (Figure 1) as weather, soils and vegetation data were available and previous studies provided the ability to compare the model outcomes with field based examples.

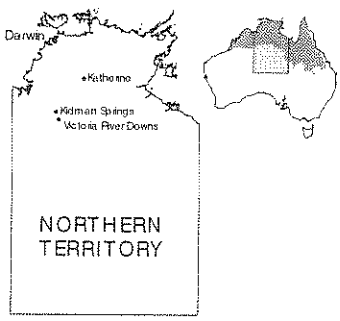

Figure 1. Distribution of Australian savannas and the location of field site in the Northern Territory

2. MODEL SIMULATIONS

SAVANNA was used to simulate a range of fire regimes and grazing pressures at Kidman Springs. Simulations were run over 40 years (1957-1996) using historical climate data from the Victoria River District [Clewett et al 1994].

A number of grazing exclosures were erected at Kidman Springs in 1973 [Foran et al. 1985]. These provided the ability to compare the outcomes of the model simulations with an area known to have had no grazing and not to have been burned for 26 years. The results of the simulations were also compared with the effects of fire reported in the literature.

Two savanna types were simulated in this study representing the range of soil types and associated vegetation grazed in the area. These included savanna woodland on red loam soils and savanna grassland on black clay soils.

2.1 Fire

The effect of fire was simulated using two fire intensities, mild and intense. These were selected to represent the patchy, early dry season fires that would be expected under fire management and the intensive and extensive, late dry season fires typical of unplanned burning after several seasons of fuel accumulation. The simulations also considered two fire frequencies with fires occurring every two and five years.

In the absence of fire, the model revealed a gradual increase in tree and shrub cover (Figure 2).

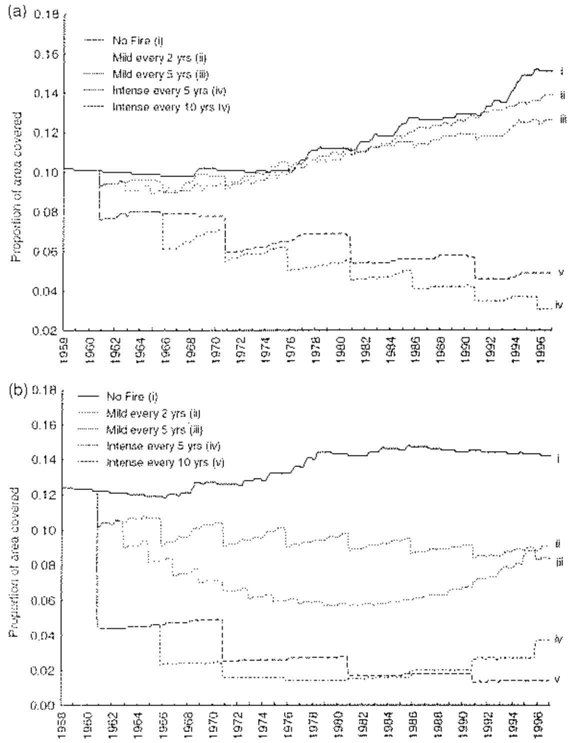

Figure 2. Simulation of the proportion of area covered by (a) trees and (b) shrubs in the woodland savanna over the range of fire intensities and frequencies

Mild fires did not affect tree cover while intensive fires reduced tree cover regardless of frequency (Figure 2a). In the absence of fire the model produced an increase in the proportion of large trees (>10 m) and a decrease in small saplings (<1.5 m) (Figure 3a).

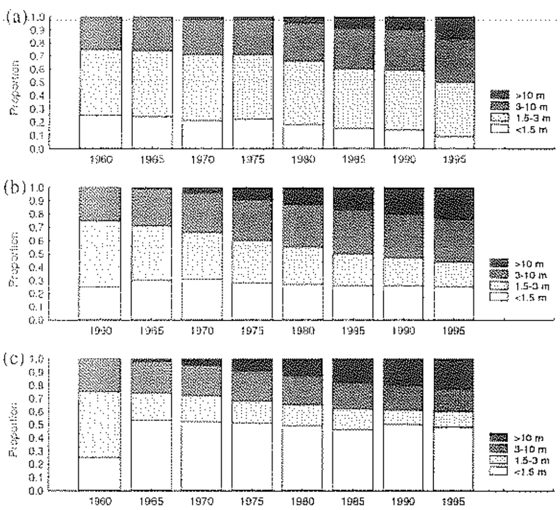

Figure 3. Proportion of trees in each size class every five years prior to (a) no fire, (b) mild fire and (c) intense fire

Fire was found to reduce the number of trees in the 1.5-3 metre size class, as these are susceptible to fire (Figure 3b,c). While saplings less than 1.5 metres are most susceptible to fire, the proportion of these individuals in the population increased. This was because all re-sprouts of damaged a top-killed larger trees were classified in this size class after each fire.

Unlike trees, shrubs are located in the flame zone, or at least scorch zone of all fires, and are therefore more susceptible to fire. The simulation showed that any fire reduced shrub cover (Figure 2b). Intensive fires had the greatest impact on shrubs. This was due to increased mortality rather than mere removal of above ground material that allows re-sprouting.

Simulations revealed a reduction in woody vegetation with fire as the mature shrubs greater than 50 centimetres high were either killed or top-killed and classified in the smaller size classes after re-sprouting (Figure 4).

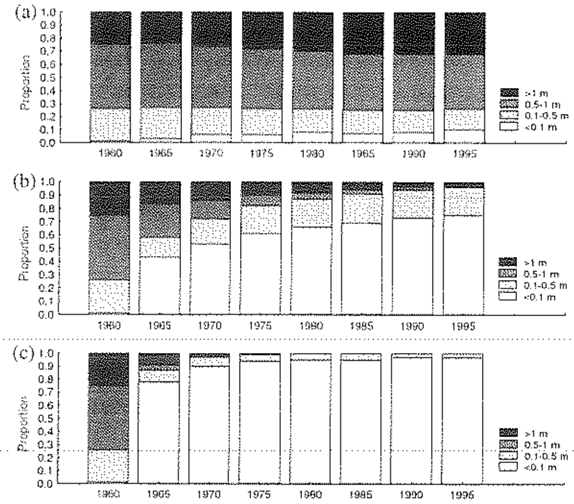

Figure 4. Proportion of shrubs in each size class every five years prior to (a) no fire, (b) mild fire and (c) intense fire

The influence of fire on the pasture species was also considered. The fire regimes simulated all produced a decline in the biomass of both perennial (Figure 5) and annual (Figure 6) grasses. Perennial grasses are most resistant to fire due to underground reserves and the fact that they are commonly dormant during the dry season when fires occur. Fire caused the greatest reductions in perennial grasses on the woodland savanna. With annual grasses, the simulated dry season fires removed dead standing material and some seed reserve, but these species were able to re-establish during the following wet season.

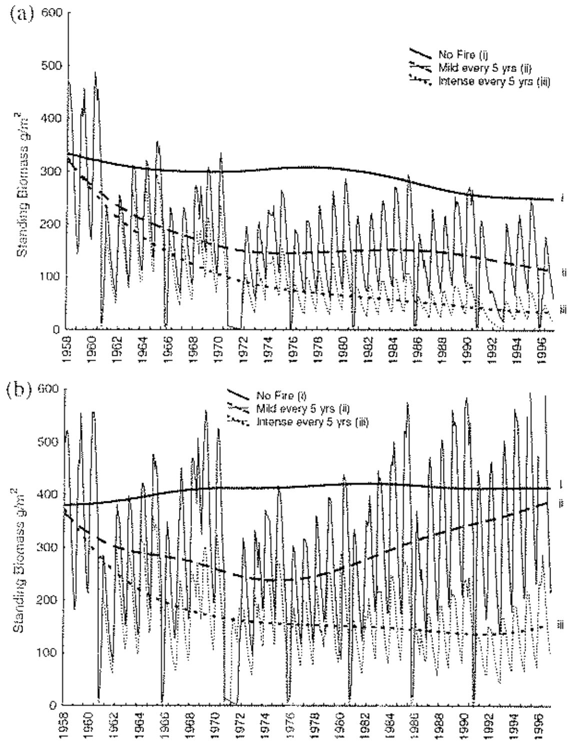

Figure 5. Simulation of standing biomass of perennial grasses in savanna (a) woodlands and (b) grasslands under different fire regimes

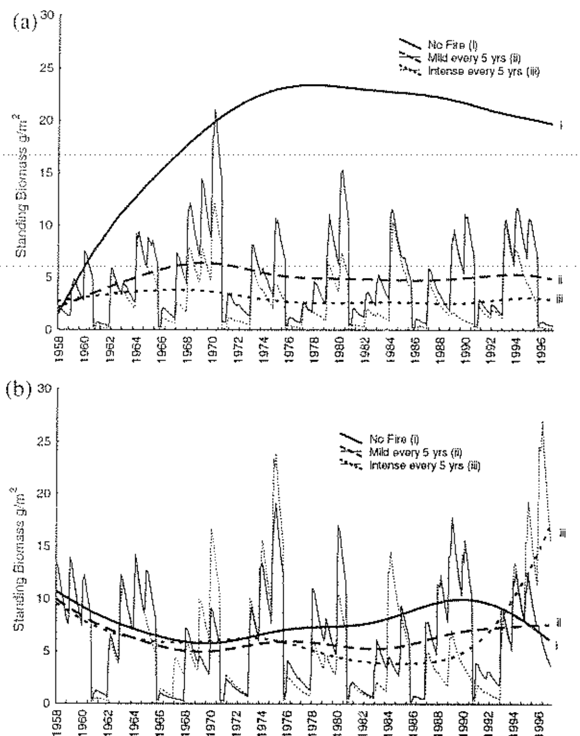

Figure 6. Simulation of standing biomass of annual grasses in savanna (a) woodlands and (b) grasslands under different fire regimes

4.1 Grazing

The model was used to simulate the effects of grazing over a range of stocking densities. For this study, moderate and heavy stocking rates were selected along with no grazing as a control. Grazing was also simulated in the two vegetation types. The model used a population dynamics sub-model to simulate herd growth and mortality based on animal condition.

Increases in the level of stocking were found to reduce the perennial grass biomass in both the savanna woodland and the savanna grassland (Figure 7). The savanna grassland was able to support both grazing intensities while providing perennial grasses. Heavy grazing on the more fragile savanna woodland with red clay soils was found to reduce the biomass of perennial grasses over the forty year simulation to low levels.

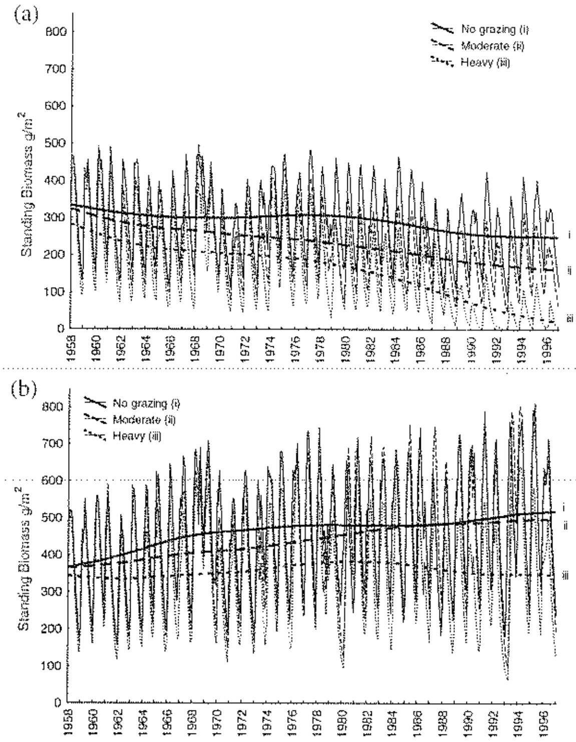

Figure 7. Simulation of standing biomass of perennial grasses in savanna (a) woodlands and (b) grasslands under moderate, heavy and no grazing

Moderate grazing on the savanna woodland was found to produce greater annual grass biomass than either heavy grazing or no grazing (Figure 8a). The annual grass biomass after forty years was found to account for around one third of the total grass biomass in the woodland savanna. At the grassland savanna perennials provided the vast majority of the herbaceous biomass.

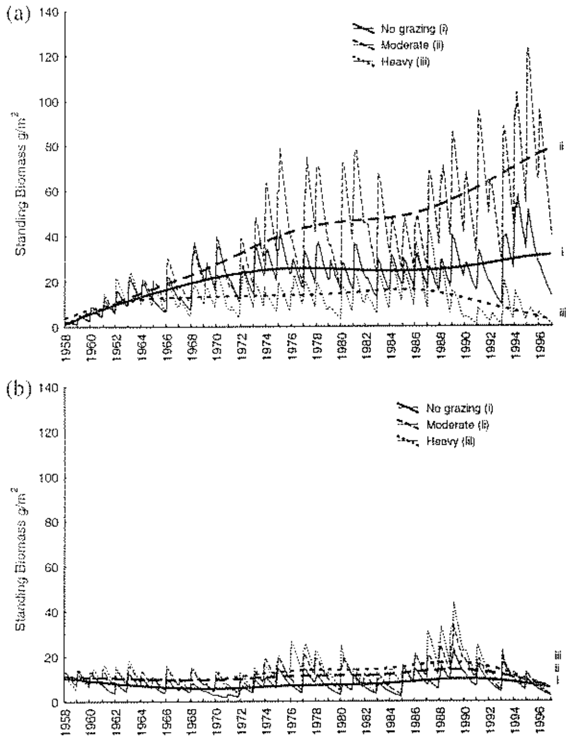

Figure 8. Simulation of standing biomass of annual grasses in savanna (a) woodlands and (b) grasslands under moderate, heavy and no grazing

3. DISCUSSION AND IMPLICATIONS FOR MANAGEMENT

These preliminary simulations have given some insight as to the effects various fire intensities and frequencies have on the tropical savannas. They confirm that fire and grazing are the dominant disturbances on the savannas and the open nature of this landscape is reliant on regular fires to be maintained.

When fire is absent, or fire frequency is low, both the model and previous field based studies suggest an increase in woody growth. This was shown to occur within the first 20 years of the simulations.

Only intense fires were observed to reduce tree cover, whereas any fire, especially intense fires, heavily impacted on shrubs. If a reduction in woody vegetation is the desired outcome of management, fire is an important tool and may be the only effective and economical means of controlling woody plant populations.

In terms of pasture condition, any fire was found to reduce the biomass of grasses. This is especially true of the perennial species in the woodland savanna that are important pasture species. Therefore, condition of pastures must be considered before fire is used to maintain or control woody vegetation.

The two savanna types were shown to respond differently to fire. The woodland savanna on red loam soils was least resistant, while the savanna grassland was able to cope with some burning.

Grazing was found to have similar effects on the savanna to fire. The woodland savanna was once again most heavily influenced by any disturbance.

The management of pastoral districts such as Victoria River District requires the use of fire in the presence of grazing. This raises a number of management implications and requires a trade-off between burning and grazing. For example, grazing will reduce fuels as the grass layer is utilised as forage for livestock. If fire is required for the management of woody vegetation, there may be insufficient fuel to sustain a fire of the required intensity to be effective. Not only is the chance of intense fire reduced, it may not be possible to use mild control fires or to stimulate grass shoots for improved pastures, therefore allowing woody species increases.

These simulations have shown that it is not sufficient to select a simple fire regime as a management tool and expect all facets of the savanna to be sustained. The use of fire will ultimately be a trade-off between the desirable outcomes of removing or controlling woody vegetation or improving areas of pasture and the undesirable effects on pasture condition.

The influence of intense fires on areas such as monsoon vine forests means any fire needs to be carefully managed. Suppressing fires from the savannas surrounding these areas could lead to damaging, intense fires, while burning with mild fires on a regular basis (biennially) was found to reduce grass biomass to low levels unsuitable for grazing.

In summary, grazing and the suppression of fire will cause an increase in woody vegetation and ultimately alter the structure of the tropical savannas. This can also lead to increased occurrence of extensive, intense fires which may be harmful to stock and infrastructure. Alternatively, using frequent fires to manage woody vegetation and reduce the chance of large fires will reduce pasture biomass and may reduce rangeland condition.

6. REFERENCES

Clewett, J.F., N.M. Clarkson, D.T. Owens, and D.G. Abrecht, Australian Rainman: Rainfall Information for Better Management. Queensland Primary Industries, Brisbane, 1994.

Coughenour, M. B., Spatial modeling and landscape characterization of an African pastoral ecosystem: a prototype model and its potential use for monitoring drought. pp. 787-810 in Ecological Indicators, Vol. I. D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (editors). *Elsevier Science*, London, 1992.

Dyer, R., M. Cobiac, L. Cafe, and T. Stockwell, Developing sustainable pasture management practices for the semi-arid tropics of the Northern Territory. Final Report, *NTA 022*, NT Primary Industry & Fisheries, Katherine, 1997.

Dyer, R., and J.J. Mott, The impact of fire no two grazed savanna communities in northern Australia in Proceedings of the VI International Rangelands Congress, Volume I, 1999.

Foran, B.D., G. Bastin, and B. Hill, The pasture dynamics and management of two rangeland communities in the Victoria River District of the Northern Territory. *Rangeland Journal*, 7, 107-113, 1985.

Mott, J.J., J. Williams, M.A. Andrew, and A.N. Gillison, Australian savanna ecosystems. pp. 56-82 in Ecology and Management of the World's Savannas. J.C. Tothill, and J.J. Mott (editors*), Australian Academy of Science*, Canberra, 1985.

Russell-Smith , J., P.G. Ryan, and R. Durieu. A LANDSAT MSS-derived fire history of Kakadu National Park, monsoonal Australia, 1980-94: seasonal effect, frequency and pachiness. *Journal of Applied Ecology, 34, 748-766, 1997.*

Russell-Smith , J., P.G. Ryan, D. Klessa, G. Waight and R. Harwood. Fire regimes, fire sensitive vegetation, and fire management of the sandstone Arnhem Plateau, monsoonal northern Australia. *Journal of Applied Ecology, 35, 829-846, 1998.*

Williams, R.J., G.D. Cook, A.M. Gill, and P.H.R. Moore. Fire regime, fire intensity and tree survival in a tropical savanna in northern Australia. *Australian Journal of Ecology*, 24, 50-59, 1999.