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Modelling the resilience of Australian savanna systems to grazing impacts

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Abstract

Savannas occur across all of northern Australia and are extensively used as rangelands. A recent surge in live cattle exports to Southeast Asia has caused excessive grazing impacts in some areas, especially near watering points. An important ecological and management question is "how resilient are savanna ecosystems to grazing disturbances?" Resilience refers to the ability of an ecosystem to remain in its current state (resist change) and return to this state (recover) if disturbed. Resilience responses can be measured using field data. These responses can then be modelled to predict the likely resistance and recovery of savannas to grazing impacts occurring under different climatic conditions. Two approaches were used to model resilience responses. First, a relatively simple mathematical model based on a sigmoid response function was used. This model proved useful for comparing the relative resilience of different savanna ecosystems, but was limited to ecosystems and conditions for which data were available. Second, a complex process model, SAVANNA, was parameterised to simulate the structure and function of Australian savannas. Simulations were run for 50 years at two levels of grazing to evaluate resistance and then for another 50 years with no grazing to evaluate recovery. These runs predicted that savanna grasslands were more resistant to grazing (changed less) than red-loam woodlands, which recovered relatively slowly from grazing impacts. The SAVANNA model also predicted that these woodlands would recover slightly slower under the climate change scenario projected for northern Australia.

Keywords: Savannas; Modelling; Grazing; Recovery

1. Introduction

Savanna systems have a continuous grass layer within a discontinuous tree layer (Scholes and Archer, 1997). Savanna types vary from those with a few low trees (savanna grasslands) to those with dense trees (savanna woodlands) (Mott et al., 1985). In Australia, savannas occur across the wet–dry tropical north (Fig. 1), occupying some $1.5 \cdot 10^6$ km^2.

Within a region, savannas are classified by which *Eucalyptus* species occurs in the tree layer and by what perennial grasses occur in the ground layer (Wilson et al., 1990). Along coasts and rivers, tropical rainforest and floodplains adjoin savannas. As rainfall declines to the south and inland from coasts, the tree density, height and canopy cover also decline, especially on clay soils (Williams et al., 1996), whereas the cover of perennial grass patches increases on sand and loam soils, but not on clays (Ludwig et al., 1999b).

In terms of area, the most extensive land use in Australian savannas is cattle grazing (Mott et al., 1985). Impacts of grazing by cattle are increasing due to growing markets in southeastern Asian countries for live cattle.

1.1. Resilience

Resilience is defined as the capacity of a system to endure under the impact of disturbances without changing in to a different system (Holling, 1973). For example, "will the perennial grass layer of a savanna persist under the impacts of cattle grazing without changing to a system dominated by annual grasses or exotic shrubs (Ash et al., 1994)?"

System resilience can take two forms. First, a system may resist change. For example, cattle grazing may have little impact on a savanna system. Second, if a system does change, will it rapidly recover? For example, cattle may graze off the tops of tussock grasses, but if their crowns remain healthy, they will rapidly recover.

Savanna grasses differ greatly in their resilience to disturbances (Walker et al., 1997). Some species such as *Chrysopogon fallax* resist change (i.e., persist under grazing), whereas others (e.g., *Themeda triandra*) decline with grazing and are slow to recover. This study suggests that the

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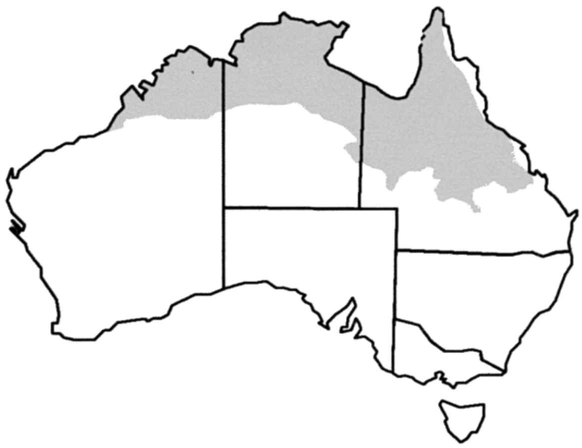

Fig. 1. Distribution of savannas (shaded) across northern Australia.

species composition of the grass layer of a savanna may change but remain largely perennial.

1.2. Grazing impacts

Grazing affects grass tussocks, leading to a decline in tussock vigour and an increase in plant mortality. Death of tussocks causes an increase in the spaces between grasses, which in turn increases the rate of runoff (McIvor et al., 1995). Without grass tussocks forming obstructions to runoff, stopping the litter and soil sediments flowing in this runoff, vital resources are lost. The landscape becomes "leaky" or dysfunctional (Tongway and Ludwig, 1997).

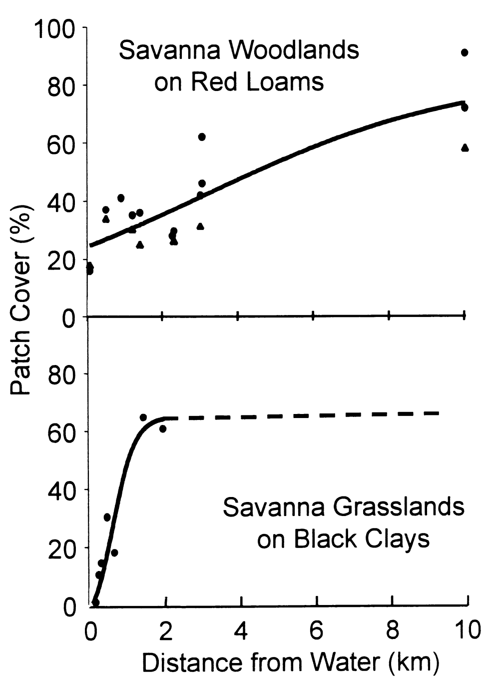

Fig. 2. Changes in the cover of perennial plant patches with distance from watering points for savanna woodlands and grasslands occurring on different soil types.

The sustainable use of savannas for cattle grazing depends on maintaining healthy perennial grass tussocks.

1.3. Climate change impacts

It has been predicted that under enhanced greenhouse conditions tropical Australia could experience a 1°C rise in annual temperature by the year 2030, while winter rainfall decreases by up to 8% and summer monsoonal rainfall increases by up to 12% (Suppiah et al., 1998). Cyclonic rains are likely to be more intense.

These projected climate changes would have direct impacts on savanna vegetation and soils. For example, increased temperatures will stress some plant species but

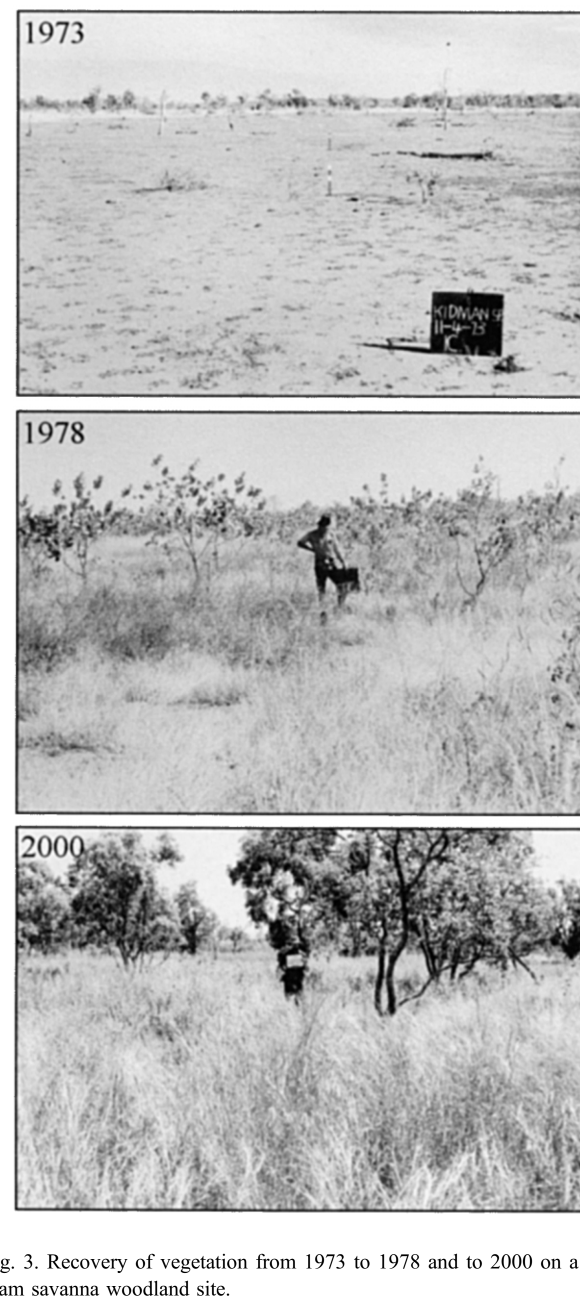

Fig. 3. Recovery of vegetation from 1973 to 1978 and to 2000 on a red-loam savanna woodland site.

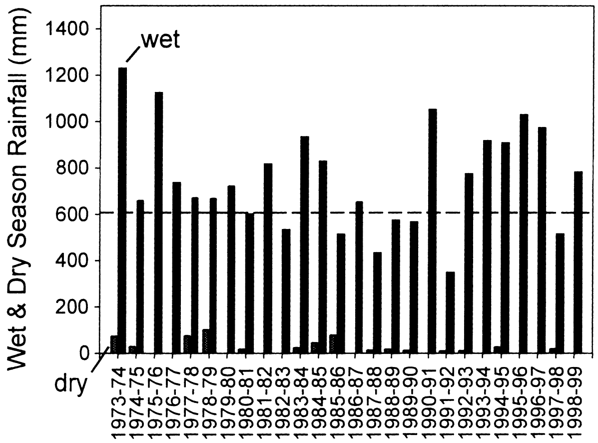

Fig. 4. Wet- and dry-season rainfalls for 1973–1999 relative to the wet season mean of 617 mm (dashed line).

favour others. These differences could cause changes in the species composition of savannas, altering the tree–grass balance (Scholes and Archer, 1997).

1.4. Aim

The aim of this study was to evaluate the resilience (both resistance and recovery) of two different tropical savannas occurring in northern Australia. We first use field observations and data to document how red-loam savanna woodlands differ from grey-clay savanna grasslands in their relative resistance to, and recovery from, cattle grazing. Then, we use a computer simulation model to explore how these two savannas differ in their responses to two levels of grazing intensity, and to a climate change scenario for northern Australia. From these results, we discuss implications for managing these savannas.

2. Field observations and data

Measuring the change in cover of perennial grasses away from cattle watering points provides insights into how resistant savanna systems are to the high impacts found near water. Distance from water can be used as a surrogate of grazing pressure — high near water, low away from water. Hypothetically, the cover of palatable plants changes as a sigmoid response function with distance from water (Ludwig et al., 1999a).

A comparison of these responses suggests that red-loam savanna woodlands in the Victoria River District (VRD), Northern Territory are far less resistant to grazing impacts than are grey-clay savanna grasslands (Fig. 2). On woodlands, the cover of perennial plant patches remained low for a considerable distance from water (5–8 km) compared to that for an ungrazed area. In contrast, on grasslands, the cover of plant patches reaches its expected maximum (dashed line) within 2 km of water.

Exclosures can be used to measure the recovery of savanna vegetation in pastures having a long history of heavy grazing. Photographs taken at the same point can be used to document how vegetation changes over time (Bastin and Andison, 1990). On a savanna woodland at Kidman Springs in the VRD, vegetation cover was very low at photo-point 1c at the time an exclosure was constructed in 1973 (Fig. 3), and standing biomass was <50 g/m^2 (Foran et al., 1985). By 1978, 5 years later, some vegetation recovery was evident, but this was largely annual grasses and exotic weeds, notably rubberbush (*Calotropis procera*). Standing biomass was up to about 200 g/m^2. In 1999, after another 21 years, these weeds were gone and the site had a high cover of perennial grasses and forbs. We measured a

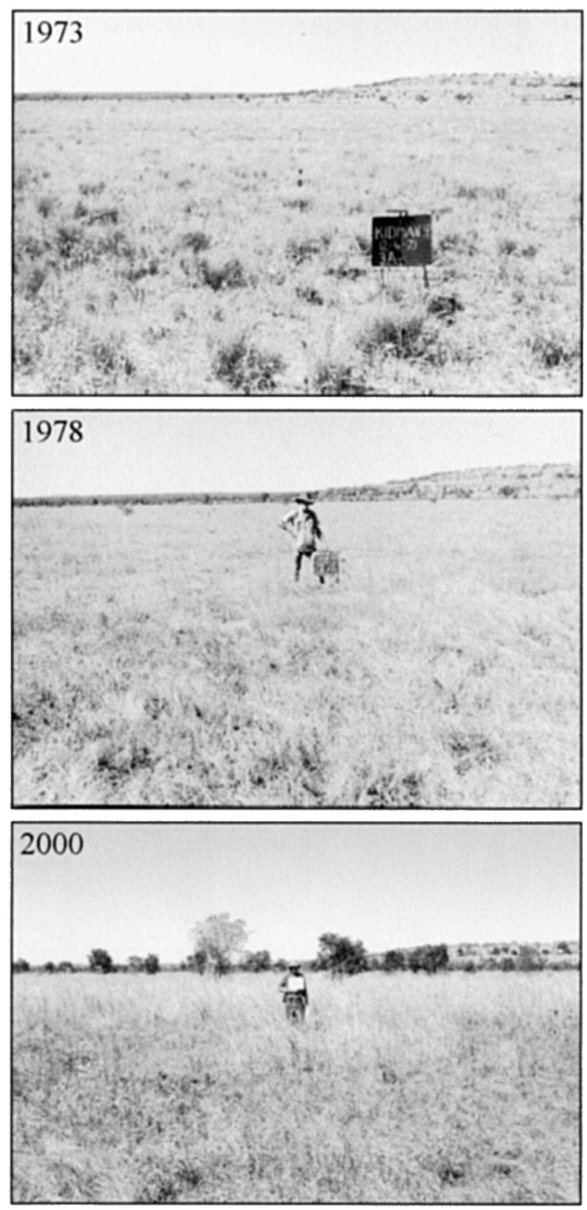

Fig. 5. Vegetation cover in 1973, 1978 and 2000 on a grey-clay savanna grassland site.

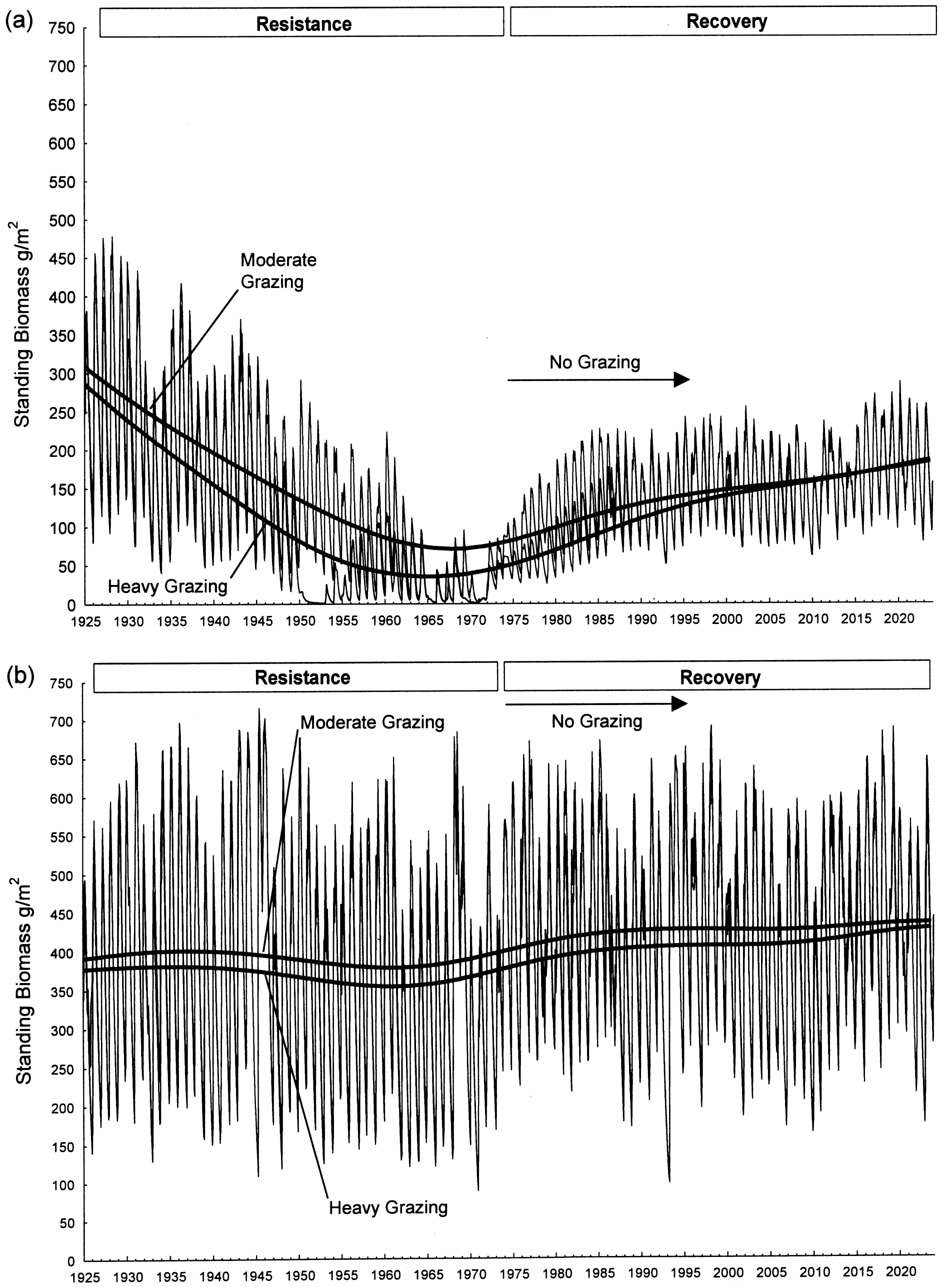

Fig. 6. SAVANNA model 100-year simulations of perennial grass biomass production for: (a) savanna woodland and (b) savanna grassland, first as impacted by moderate and heavy cattle grazing for a 50-year period to evaluate resistance, and then for a 50-year period with no grazing to evaluate recovery.

standing biomass of 264 g/m^2 at 1c in May 1999. Trees had reestablished and grown to a height of 5–6 m in these savanna woodlands (as seen at photo-point 1c in June 2000; Fig. 3).

During this period from 1973 to 1999, wet-season rainfall (Oct.–Apr.) was usually above the long-term wet-season mean of 617 mm (Fig. 4), which is based on a 112-year record for Victoria River Downs. The wet season of 1991–1992 was well below average, whereas dry-season rainfall is always low.

On savanna grassland at Kidman Springs, vegetation cover was relatively high in 1973 even after decades of cattle grazing (photo-point 3a; Fig. 5), with standing biomass at about 100 g/m^2 (Foran et al., 1985). By 1978, 5 years later, grass cover was still high, and standing biomass was 110 g/m^2. Grass cover remained high in May 1999, when we estimated standing biomass to be about 150 g/m^2. Trees were uncommon on this grey cracking-clay site in 1973, but had noticeably increased after 27 years (photo-point 3a; June 2000).

3. Savanna modelling

Simulation modelling is a valuable tool for exploring situations that would be very difficult and costly to examine with field experiments. A simulation model, SAVANNA, developed to simulate the structure and function of savannas (Coughenour, 1992), is a spatially explicit, process-oriented model composed of submodels for water balance, plant production, herbivory and population dynamics. SAVANNA was parameterised using relationships derived from field grazing and fire studies on Kidman Springs (Foran et al., 1985; Dyer et al., 1997). These studies document how standing biomass of perennial grasses in savanna woodland and grassland respond to grazing and fire treatments. SAVANNA was driven by weather data from the VRD (Clewett et al., 1994).

The model, which uses a weekly time-step, was run for 100 years. Simulation scenarios included two levels of stock, moderate and heavy (20 and 50 head/km^2, respectively), and a climate change scenario of a 1°C rise in mean annual temperature and a 10% increase in wet-season rainfall, which occurred in high-intensity storms. Because vegetation cover was reduced near watering points on Kidman Springs (Fig. 2), simulation scenarios were based on savanna woodland and grassland sites located 10 and 5 km from water, respectively.

3.1. Grazing impact simulations

Over the 100-year simulations, resistance to grazing was evaluated for a 50-year period from 1923 to 1973. Then, cattle were removed to mimic the effect of the exclosure built in 1973. Recovery of the vegetation was then explored for the next 50 years (up to 2023). Savanna woodlands on red-loams have low resistance to both moderate and heavy grazing. Declining trend-lines for standing biomass of perennial grasses over the 1923–1973 period (Fig. 6a) indicates this. In contrast, savanna grasslands on grey-clays are very resistant to grazing as indicated by little change in biomass trends over this 50-year period (Fig. 6b).

After the cattle were removed in 1973, the savanna woodlands recovered over the next 20 years (Fig. 6a), which is confirmed by our field biomass data and observations (see Fig. 3).

The savanna grasslands showed a recovery in biomass over about a 10-year period, but this only had to be a small change because biomass was already relatively high at the start of the recovery period in 1973. Our field data and observations (see Fig. 5) also confirm these results.

3.2. Climate change impact simulations

Our 100-year simulations of savanna woodlands and grasslands suggest that the projected climate change for northern Australia had little impact on these systems. The only apparent effect was a slightly slower and delayed recovery of grass biomass for woodlands in the 50 years after grazing was removed (for brevity, these simulation results are not shown, but are available from the authors).

4. Implications for management

Our field observations (photo-points), data (exclosure biomass measures) and SAVANNA model simulations for Kidman Springs clearly indicate that eucalypt woodlands on calcareous red-loam soils need to be managed very wisely if perennial grass biomass is to be maintained at a relatively high level. These ecosystems appear to be much less resilient in terms of both resistance to, and recovery from, cattle grazing impacts than grassland systems on grey-clay soils. These results confirm experimental studies on Kidman Springs (e.g., Dyer et al., 1997).

The simulation results presented here need to be viewed cautiously as the SAVANNA model requires further verification, particularly for other savanna systems in northern Australia. The savannas of Kidman Springs in the VRD are but one small part of the vast savannas of northern Australia.

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