VEGETATION CHANGES IN A SEMIARID TROPICAL SAVANNA, NORTHERN AUSTRALIA: 1973-2002

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Abstract

We measured vegetation changes inside and outside two exclosures built in 1973 on red calcareous loam soils located in Conkerberry Paddock on Victoria River Research Station in northern Australia. These two exclosures were unburnt since their establishment in 1973 until exclosure 1 was unintentionally burnt late in the dry season (October) of 2001. Data from permanent transects and examples from photopoints illustrate that from mostly bare soils in 1973, total pasture biomass recovered relatively rapidly both inside and outside exclosures (in about five years). This initial recovery was primarily due to the establishment of annual grasses and forbs. After this five year period, there was a consistent increase in the biomass of perennial grasses, such as *Heteropogon contortus* and *Dichanthium* spp. Also in the first five years after exclosure, the exotic shrub, *Calotropis procera*, invaded the study area, but then largely disappeared in a period of lower wet-season rainfall in the late 1980s. The density of native tree species, particularly *Hakea arborescens*, *Eucalyptus pruinosa* and *Lysiphyllum cunninghamii* increased in general, but more so inside one or other of the exclosures. Although the late dry-season fire of 2001 reduced the density of larger *H. arborescens* and *L. cunninghamii* inside the exclosure at Site 1, this effect was not apparent for smaller trees and for trees outside this exclosure. Our findings show that savanna vegetation can change massively in the medium term (29 years) and that exclosure from cattle grazing can contribute to our understanding of the role of livestock in such change. However, exclosures by themselves do not provide adequate information about the processes leading to vegetation change – replicated experimental studies are needed. That substantial increase in the biomass and proportion of perennial grasses occurred with light to moderate cattle grazing implies that these rangelands can be managed for production, although control of woody vegetation is an issue.

Key words: vegetation change; exclosure; semi-arid tropics; tree-grass balance; *Heteropogon contortus*; *Eucalyptus; Hakea*

Introduction

Long term exclosure studies are useful for comparing how vegetation changes in response to climatic fluctuations and to livestock grazing and fire (Noble 1977, Valamanesh 1999). Vegetation changes inside versus outside exclosures can indicate the effects of livestock grazing, provided that measurements are made inside and outside at the same time and in similar parts of the landscape with respect to soils, local geomorphology and fire history. Exclosures can also demonstrate to rangeland managers the potential benefits of destocking (spelling) paddocks (Harrison and Shackleton 1999). Vegetation condition within exclosures can provide managers with a reference for them to compare and evaluate pasture condition outside exclosures to assist with stocking rate decisions. Of course, the manager must also evaluate the state of vegetation within an exclosure given its recovery from treatment prior to exclosure.

Notable examples of long-term vegetation studies in rangelands include the Jornada Experimental Range, southern New Mexico, where vegetation change data have been acquired since 1915

(e.g. Gibbens and Beck 1988, Havstad *et al.* 2000), and the Koonamore Vegetation Reserve, South Australia, established in 1925 (Noble 1977). Further examples of vegetation change studies in rangelands include photographic sequences obtained from 1955-1998 in KwaZulu-Natal, South Africa (Hoffman and O'Connor 1999), from 1941-1995 in south-west Queensland (Freudenberger 1997), and from 1964-1992 in Israel (Carmel and Kadmon 1999). Field data and photographs were used in combination to examine vegetation changes from 1976-1996 in central New Mexico (Ryerson and Parmenter 2001) and from 1966-1995 in Cape York Peninsula (Crowley and Garnett 1998).

Photographs and plot data describing vegetation have also been collected from 1973 to 2002 on Victoria River Research Station at Kidman Springs in the Northern Territory (Foran *et al.* 1985, Bastin and Andison 1990). In this paper, we document vegetation changes over this 29-year period using a time-series of data from permanent plots and transects and with photographs taken at fixed points both inside and outside two exclosures.

Methods

The study was conducted in Conkerberry Paddock (16° 4' S, 130° 57' E) on the Victoria River Research Station at Kidman Springs, which is located 40 km north of Victoria River Downs Homestead and 220 km south west of Katherine (see Foran *et al.* 1985 for details). Former grazing use as a major stock reserve and the presence of feral donkeys prior to establishing the research station in 1967 had severely damaged some vegetation types, particularly near permanent water holes (Foran *et al.* 1985).
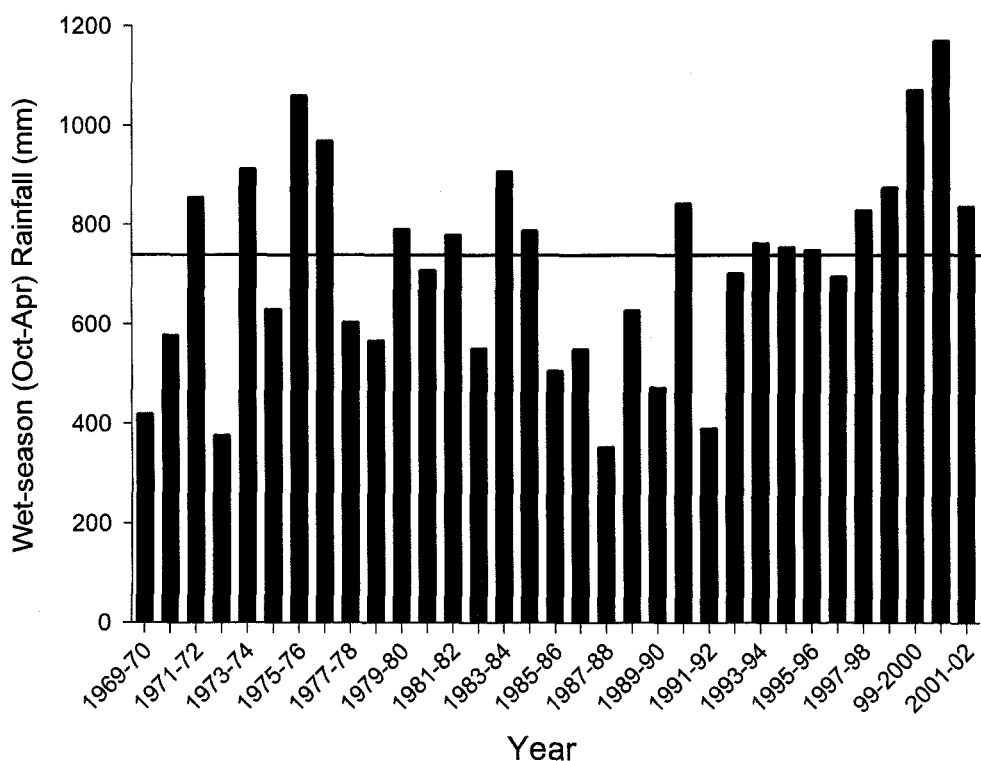
Two exclosures, each approximately 500 m square, were erected in 1973 on calcareous red loams belonging to the Calcareous Red Earth soil family (Gc1.22, Northcote *et al.* 1975). Exclosure 1 was established on an area of largely bare soil assessed to be in poor rangeland condition and exclosure 2 was on an area of largely annuals that was assessed in relatively good condition (Foran *et al.* 1985). Hereafter, these two areas with exclosures 1 and 2 are referred to as Sites 1 and 2. These exclosures were unburnt since 1973 until an accidental fire burnt inside and outside exclosure 1 in October 2001 [Research Station management records; Don Cherry, pers. comm.]. The areas outside these two exclosures in Conkerberry Paddock were grazed by experimental cattle herds throughout the study period but only at about 5-7 hd/km², a light-moderate level for the region (see Sullivan and O'Rourke 1997). Although Agile Wallabies live and graze inside and outside these exclosure, their numbers always appeared to be low based on our field observations. We do not have any Agile Wallaby density data, however, their numbers were so low in spot-light surveys in Conkerberry Paddock in October 1997 that mammals were not included in a faunal analysis for the area (Woinarski *et al.* 1999).

Wet-season rainfall was well above the 749 mm median in the mid 1970s and latter 1990s – early 2000s (Fig. 1), considerably below the median in the late 1980s and close to the median in most other years.

Herbage biomass was measured by clipping individual species in June of each year between 1974 and 1979, and again in May 1999 and June 2002. Species were harvested within five randomly placed 1 m² quadrats surrounding six permanently marked locations inside and outside each exclosure, giving a total of 120 clipped quadrats (30 for each exclosure treatment). Samples were oven dried to obtain dry weight. Additional biomass data were obtained in June 1989 and 1994 by estimating yield and composition using BOTANAL (Tothill *et al.* 1992) within 15 randomly placed 1 m² quadrats at each of the six permanently marked sampling locations. Mean yields (± s.e.) for inside and outside each exclosure (Sites 1 and 2) were estimated from these biomass data for the six permanent sample locations.

Woody species were categorised as "tree" or "shrub" and their density recorded by height class (small shrubs ≤0.5 m, large shrubs >0.5 m, small trees ≤2 m, large trees >2 m) within fixed 0.14 ha areas at each of the permanent sampling locations. Mean densities (± s.e.) for inside and outside exclosures at Sites 1 and 2 were estimated using the six permanent sampling locations inside each exclosure and the six samples outside each exclosure. A colour 35 mm landscape photograph was also taken at these permanent locations at the time of each data collection.

Repeated measures analysis of variance was used to explore whether there was a significant change (slope) across time (years since exclosure) and, if so, whether changes across time differed for inside and outside the exclosures (treatments). If changes across time appeared to be non-linear, quadratic and cubic polynomials were explored using SYSTAT repeated measures procedures (Wilkinson 1999). Herbage biomass measures were repeated ten times at uneven intervals (1, 2, 3, 4, 5, 6, 16, 21, 26 and 29 years after exclosure) and woody density measures were repeated seven times (0, 3, 5, 16, 21, 26 and 29 years after exclosure). These uneven time intervals were incorporated in the SYSTAT repeated measures analyses.

Fig. 1. Total wet season (October-April) rainfall, Victoria River Research Station, NT, for the period 1969-2002. The horizontal line indicates the median wet season rainfall of 749 mm over this period.

Results

Prior to exclosure in 1973, Site 1 had extensive areas of bare soil and a sparse covering of annual grasses and forbs (Fig. 2a). By 1978 vegetation cover had visibly increased, largely because of annual grasses and the exotic shrub, rubberbush *(Calotropis procera)*, (Fig. 2b). *C. procera* was replaced by native trees and shrubs by 1989 (Fig. 2c) and much of the formerly bare soil
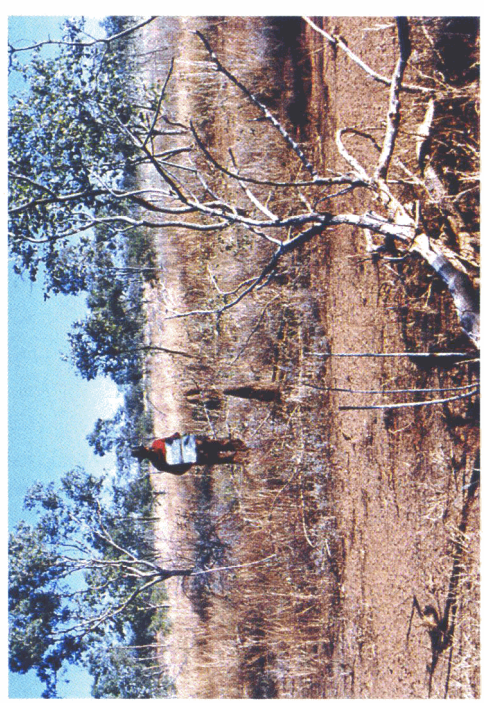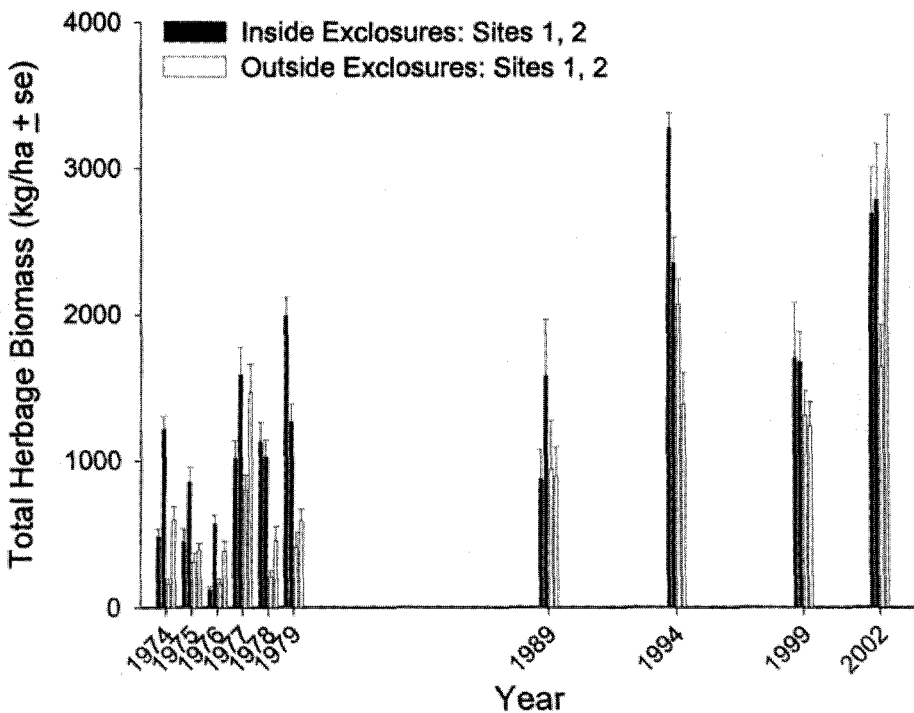
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Fig. 2. Sequence of photographs from a fixed location (1C) inside exclosure 1 for (a) April 1973, prior to exclosure construction, (b) June 1978, (c) June 1989, (d) June 2000, (e) November 2001, after a hot fire, and (f) June 2002.

and annual-covered areas had been colonised by the perennial, black spear grass *(Heteropogon contortus)* (Bastin and Andison 1990). Native tree species continued to increase in size and density by 2000 (Fig. 2d). A hot fire in the late dry season of 2001 appeared to reduce this woody thickening (Fig. 2e) but growth during the following wet-season (Fig. 2f) returned the site to an appearance similar to that in 2000 before the fire. (Note: see Dunlop *et al.* 1995 for plant species' nomenclatures.)

Herbage biomass

For each year of sampling since 1978, the mean biomass of all herbage species (grasses and forbs) recorded at the end of the wet-season growth period inside exclosures usually exceeded that outside exclosures (Fig. 3). Repeated measures analysis indicated that there was a significant linear increase in total herbage biomass with time (P < 0.01), but this increase was not different for inside and outside exclosure treatments (P = 0.64).

Fig. 3. Mean above-ground biomass (kg/ha $\pm$ standard errors, se) for all herbs (grasses and forbs) measured inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Biomass is the green standing crop at the end of the wet-season in the year indicated.

Amongst the components of total herbage, the mean biomass of perennial grasses, both inside and outside exclosures, has increased in most years since biomass measurements commenced (Fig. 4a). This increase across time was significant (P < 0.01). Although perennial grasses appeared to have a greater increase (steeper slope) inside exclosures than outside, this difference was marginally insignificant (P = 0.055) due to low degrees of freedom (only two true replicates).
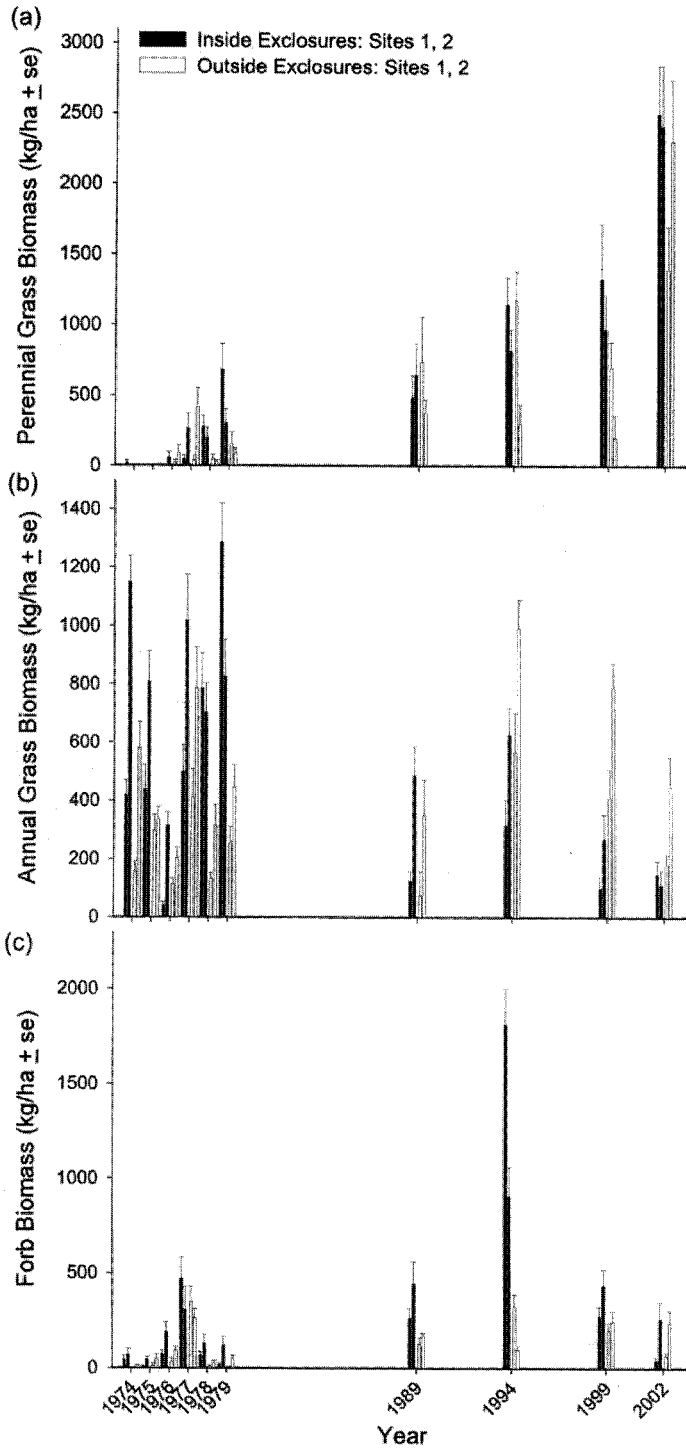
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Fig. 4. Mean above-ground biomass (kg/ha $\pm$ se) for (a) perennial grasses, (b) annual grasses and (c) forbs measured inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Biomass is the green standing crop at the end of the wet-season in the year indicated.

Mean biomass of annual grasses has fluctuated considerably since 1974 (Fig. 4b) but time was not a significant factor (P = 0.10) because of the fluctuations across years. Annual grass biomass was higher inside exclosures compared to outside immediately following exclosure, especially in 1974, 1978 and 1979, but this trend was reversed in later years (1994, 1999 and 2002). Linear slopes were significantly different between inside and outside exclosures (P = 0.023).

Broad-leaved forbs have made a relatively small contribution to mean total herbage biomass in all years apart from 1994 (Fig. 4c) when the annual forb, *Ptilotus exaltatus*, was a major component of pastures, but only inside exclosures. This spike in *Ptilotus biomass* in 1994 caused the overall change across years to be significant (P = 0.005) and the slope for forb biomass inside exclosures to be significantly higher than for outside (P = 0.018).

The increase in mean biomass of perennial grasses outside exclosures was largely attributable to *Heteropogon contortus* (Fig. 5a). This species comprised 83% of total perennial grass biomass in 1989, 73% in 1994, 87% in 1999 and 95% in 2002. *H. contortus* was also an important contributor to the increasing biomass of perennial grasses inside exclosures, comprising up to 56% of that group by 1989 and 70% in 2002. These *H. contortus* biomass increases were significant across time (P = 0.002) and did not differ between inside and outside exclosures (P = 0.52). However, areas inside and outside exclosures also had several other perennial grasses with the most abundant being *Dichanthium* species (Fig. 5b), which comprised 61% of the total perennial grass biomass inside exclosures in 1994. Although *Dichanthium* appeared to increase with time, especially inside the exclosure at Site 1, its low biomass inside exclosure 2 and outside both exclosures caused a non-significant overall change (linear slope) across time (P = 0.25) as well as for between inside and outside exclosures (P = 0.38).

The annual/short-lived perennial grass *Enneapogon polyphyllus* was common throughout the study period (Fig. 5c). At the commencement of exclosure in 1973, Site 2 was dominated by *E. polyphyllus* (Foran *et al.* 1985). The mean biomass of *E. polyphyllus* initially decreased from 1974 to 1976 inside and outside exclosures, and then increased, reaching a peak inside exclosures in 1979, where its mean biomass was considerably greater than that outside exclosures. Biomass of *E. polyphyllus* then declined, and by 1999 the mean biomass of this short-lived grass outside exclosures was greater than that inside. Overall, these biomass fluctuations did not have a significant trend (linear slope) across time (P = 0.092) and the slopes for inside and outside exclosures were not significantly different (P = 0.094).
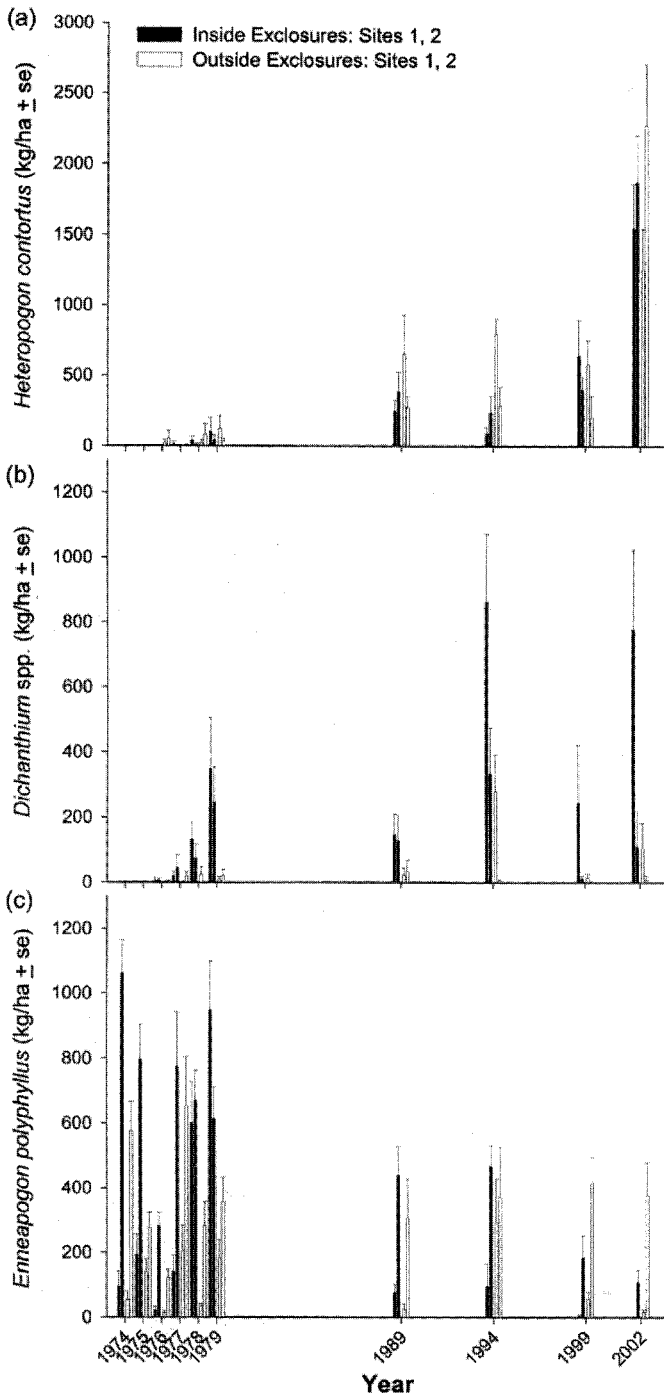
Density of woody species

The mean density of trees and shrubs was initially low in 1973, but shrub density then increased massively inside the exclosures by 1978 (Fig. 6a), but subsequently declined to a moderate density (~200/ha). This trend in shrub density across years was significantly fit by a quadratic polynomial (parabolic curve) (P < 0.01), and the curve for inside exclosures was significantly higher than for outside (P = 0.012).
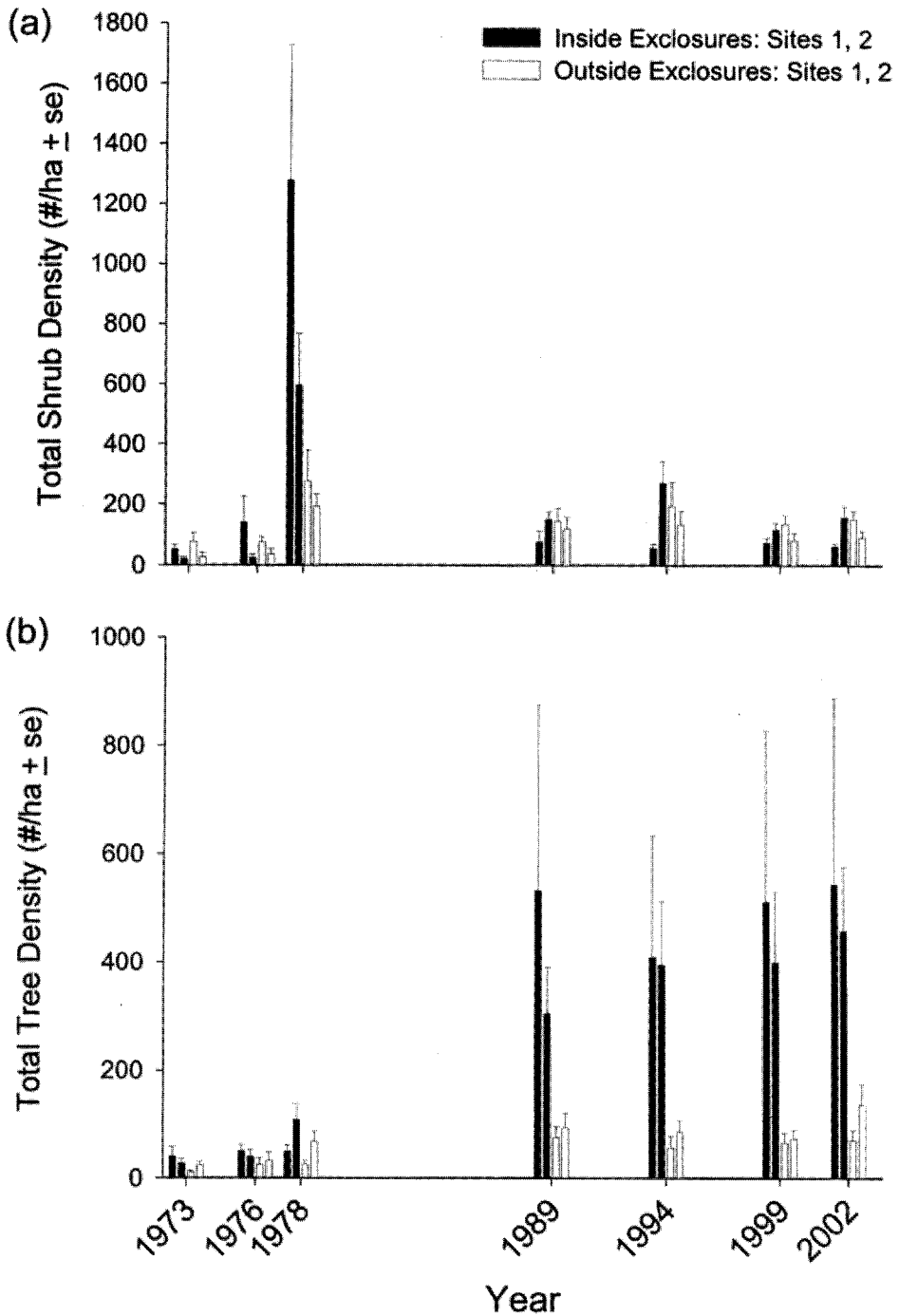
Overall, there was a significant linear increase in tree density across years (P = 0.010) (Fig. 6b). This increase was slow from 1973 to 1978, both inside and outside exclosures, followed by a large increase in 1989, but only inside exclosures. The linear slope for increasing tree density inside exclosures was significantly greater than that for outside (P = 0.018).

As previously illustrated (Fig. 2b), the high shrub density in 1978 was almost entirely due to the exotic species, *Calotropis procera* (Fig. 7a). Large *C. procera* shrubs (> 0.5 m in height) subsequently significantly declined (P = 0.008) to a very low density both inside and outside exclosures. Small *C. procera* shrubs similarly decreased in density but this decline was not significant (P = 0.16) due to high variability and low replication (two Sites).
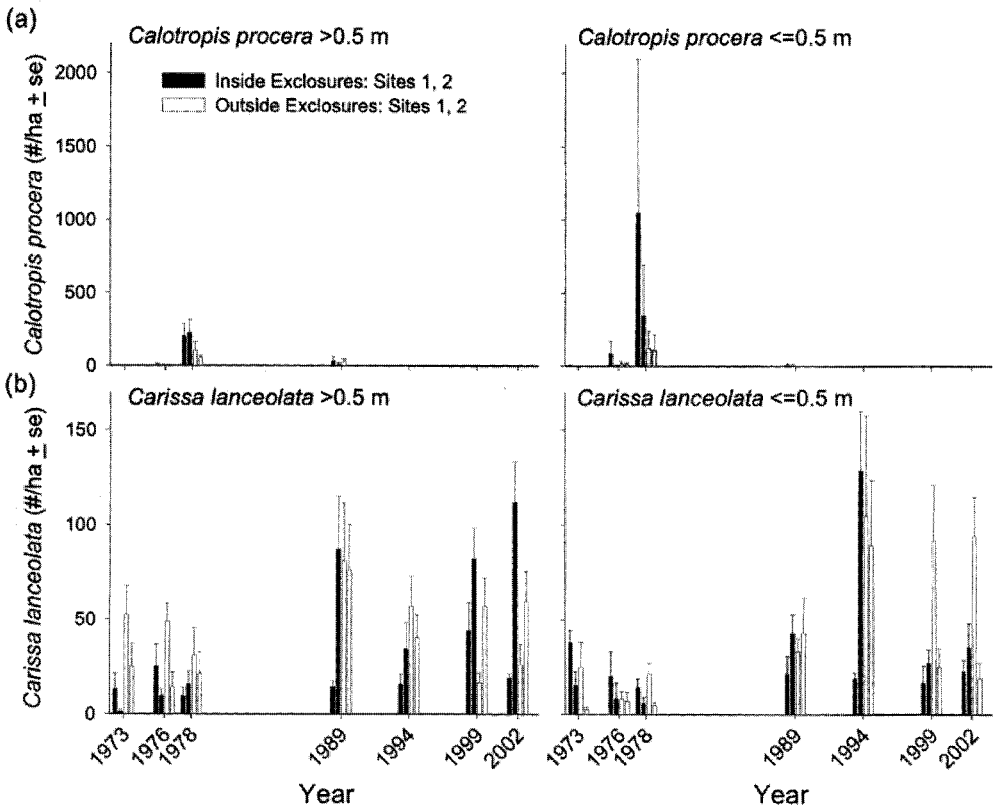
Fig. 5. Mean above-ground herbage biomass (kg/ha $\pm$ se) for (a) *Heteropogon contortus*, (b) *Dichanthium* spp. and (c) *Enneapogon polyphyllus* measured inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Biomass is the green standing crop at the end of the wet-season in the year indicated.
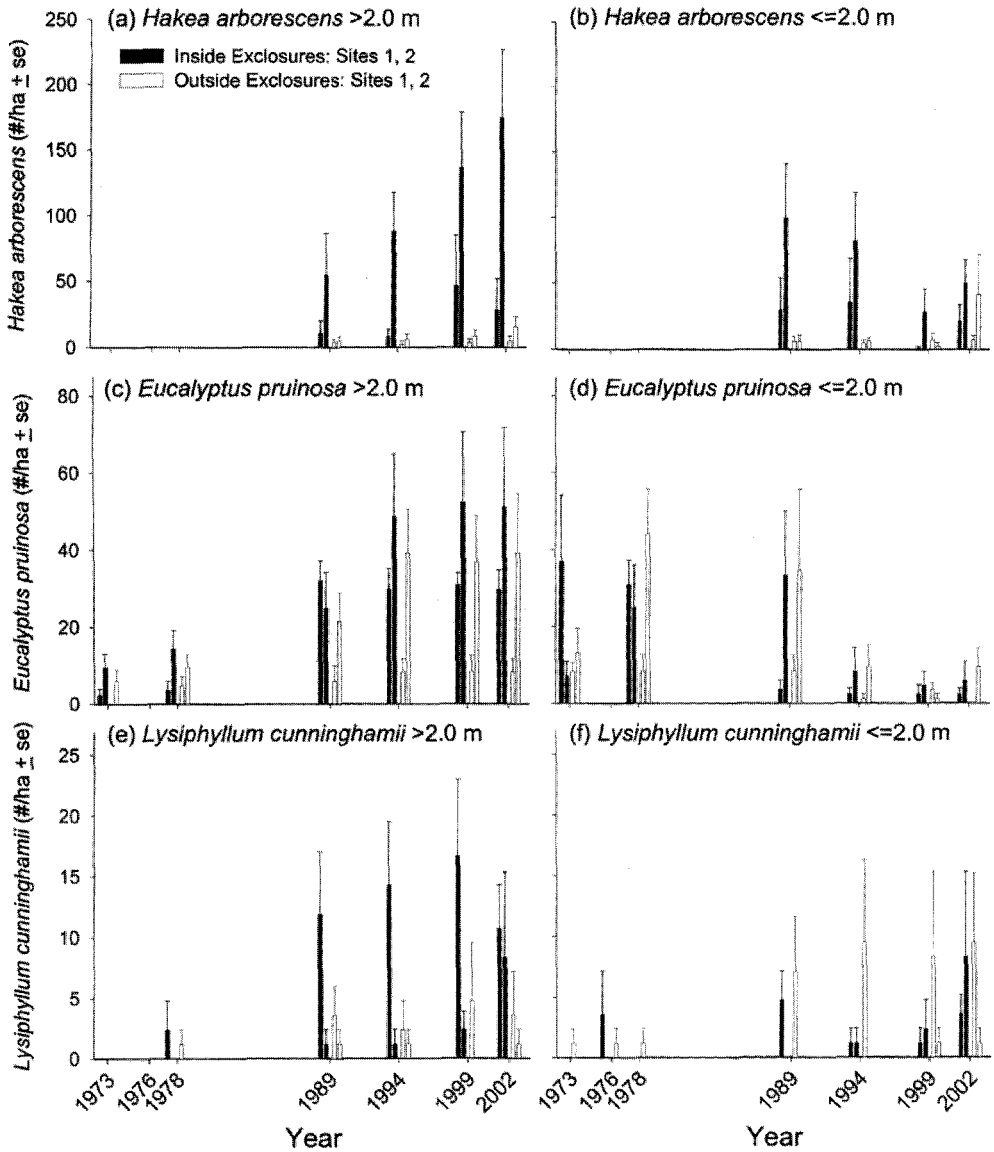
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Fig. 6. Mean density (#/ha ± se) for (a) shrubs in two height classes: >0.5 m and <=0.5 m, and for (b) trees in two height classes: >2.0 m, and <=2.0m, counted inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Counts were taken within permanent 0.14 ha sampling locations at the end of the wet-season in the year indicated.

Carissa lanceolata has been a common shrub inside and outside exclosed areas, especially since 1989 (Fig. 7b). Its density has fluctuated on both areas consistent with its short-lived nature; repeated measures of large and small *C. lanceolata* density did not significantly change across years (P = 0.32 and P = 0.16, respectively).

Fig. 7. Mean density (#/ha $\pm$ se) for *Calotropis procera* shrubs in two height classes: (a) >0.5 m and (b) <=0.5 m, and for *Carissa lanceolata* shrubs in two height classes: (c) >0.5 m and (d) <=0.5 m counted inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Counts were taken within permanent 0.14 ha sampling locations at the end of the wet-season in the year indicated.

The main contributor to increased tree density has been *Hakea arborescens* (Figs. 8a,b). This species was first recorded in 1989. *Hakea arborescens* individuals >2 m have continued to increase in mean density, especially inside exclosures, while maintaining a low density outside exclosures since 1989. However, due to high variability between Sites and low replication (two), this change was not significant (P = 0.24). After being recorded in 1989, smaller *H. arborescens* have continued to appear inside and outside exclosures. Again, these changes were not significant (P = 0.12). The hot, late dry-season 2001 fire at Site 1 reduced the density of large *Hakea* from 46.4 individuals per hectare present in 1999 down to 28.6 in 2002 (Table 1). However, this reduction in larger *Hakea* was not evident outside the exclosure at this site and it was not evident for small *Hakea*.

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Fig. 8. Mean density (#/ha ± se) for *Hakea arborescens* trees in two height classes: (a) >2.0 m and (b) <=2.0 m, for *Eucalyptus pruinosa* trees (c) >2.0 m and (d) <=2.0 m, and for *Lysiphyllum cunninghamii* trees (e) >2.0 m and (f) <=2.0 m counted inside and outside exclosures located in Conkerberry Paddock, Victoria River Research Station, NT. Counts were taken within permanent 0.14 ha sampling locations at the end of the wet-season in the year indicated.

Large *Eucalyptus pruinosa* have also increased in density throughout this study and now occur at a low to moderate density (<55/ha, Fig. 8c), whereas the density of small *E. pruinosa* has decreased (Fig. 8d). When averaged over all years of measurement, differences in mean densities for large and small *E. pruinosa* inside and outside exclosures were significant (P < 0.01 and P = 0.037, respectively). However, linear trends based on repeated measures across time were not significant (P = 0.064 and P = 0.21, respectively), probably due to high variability (standard errors) and low replication (two Sites). The 2001 fire did not appear to affect the density of this species, although no small individuals were observed outside the exclosure at Site 1 in 2002 (Table 1).

Table 1. Mean density $\pm$ SE (#/ha) for selected tree species at Site 1 located in Conkerberry Paddock, Victoria River Research Station, NT prior to and following the hot late dry-season 2001 fire. Counts were taken within permanent 0.14 ha sampling locations at the end of the wet-season in the year indicated.

Species	Height Class	Inside Exclosure 1		Outside Exclosure 1	
		1999	2002	1999	2002
Hakea arborescens	>2m	46.4 ± 38.3	28.6 ± 23.1	3.6 ± 2.4	4.8 ± 3.5
	≤2m	1.2 ± 1.2	21.4 ± 12.6	7.1 ± 4.5	7.1 ± 3.2
Eucalyptus pruinosa	>2m	31.0 ± 3.0	29.8 ± 5.0	8.3 ± 4.3	8.3 ± 3.4
	≤2m	2.4 ± 2.4	2.4 ± 1.5	3.6 ± 1.6	0.0 ± 0.0
Lysiphyllum cunninghamii	>2m	16.7 ± 6.3	10.7 ± 3.6	4.8 ± 4.8	3.6 ± 3.6
	≤2m	1.2 ± 1.2	3.6 ± 1.6	8.3 ± 7.0	9.5 ± 5.7

Large *Lysiphyllum cunninghamii*, although present at a lower density than *E. pruinosa*, have also shown an increase in mean density, especially within exclosures, since 1978 (Fig. 8e). However, this change in density with time (slope) was not significant (P = 0.13). The density of smaller *Lysiphyllum* also appears to have increased over the 29 years (Fig. 8f), but this trend (slope) was not significant (P = 0.20). Although there was a reduction in larger *Lysiphyllum* inside the exclosure at Site 1 after the 2001 fire, this decrease in density was not strongly evident outside the exclosure. There was a slight increase in density of smaller *Lysiphyllum* between 1999 and 2001 (Table 1).

Discussion

Vegetation biomass, density and photopoint data collected at Kidman Springs over a 29-year period from 1973 to 2002 demonstrated that savanna vegetation on calcareous red soils can change substantially through time. Starting on areas either bare or with annual grasses in 1973, dramatic vegetation changes were evident, especially inside exclosures where perennial grasses (principally *Heteropogon contortus* and *Dichanthium* spp.) now have a high biomass. However, even outside the exclosures where light to moderate cattle grazing still occurs, increases in the biomass of perennial grasses have occurred. The exotic shrub, *Calotropis procera*, initially erupted to reach a high density, especially inside exclosures, but subsequently declined to almost disappear and was replaced by several native tree species.

Rainfall above the wet-season median in the mid 1970s (Fig. 1) probably helped perennial grasses become established, most notably within the exclosures, and contributed to the proliferation of *C. procera*. It was then likely that subsequent below-median rainfall in the 1980s contributed to the demise of this exotic species. Native tree species also established during this decade and rainfall close to, or above, the median through the 1990s and early 2000s, and continued absence of fire probably benefited their survival and growth.

We observed that bare areas were progressively colonised by *Heteropogon contortus* with photopoint sequences indicating that it spread laterally from established tussocks (e.g. Fig. 2). *H. contortus* seeds prolifically (see Grice and McIntyre 1995 for a comprehensive review of the species) although heavy grazing reduces inflorescence density per plant and hence seed production (D. Orr, pers. comm.). The seed spikelet has a hard, pointed base and a hygroscopically active awn that aids in seed burial (Tothill 1969). Burning, and subsequent grazing management promotes an increase of *H. contortus* (Orr *et al.* 1997, Orr and Paton 1997). Heating of seed buried near the surface is thought to break dormancy (Campbell 1995) and reduced, or deferred, grazing pressure promotes successful establishment of germinating seedlings. Our study sites were not burnt until October 2001 but it is possible that high solar insolation on bare soil prior to that may have emulated burning in its effect on seed dormancy. However, the simple accumulation of seed supply through time could also plausibly explain the observed dominance of *H. contortus* in latter years.

Livestock grazing pressure in Conkerberry Paddock was continuous at light to moderate levels throughout this study, ranging from 5-7 hd/km^2 (e.g. Sullivan and O'Rourke 1997). We observed little evidence of *Heteropogon contortus* plants having been appreciably grazed at the time of biomass harvests. Thus, it was likely that many seedlings were able to successfully establish and grow into mature tussocks progressively increasing the biomass contributed by this species. However, there is substantial evidence that heavy grazing of *H. contortus*, particularly in drought, has contributed to the decline of this species in northern Australian pastures (McKeon *et al.* 1990, Tothill and Gillies 1992, Orr *et al.* 1994, Grice and McIntyre 1995) and thus a key aspect in its increase at our sites was undoubtedly the moderate stocking rate and availability of other pasture species for grazing.

Calotropis procera reached its highest density in 1978 (Foran *et al.* 1985), but then declined to a low density both inside and outside exclosures by 1989. It was still present in 1999 and 2002, but very rare. The decline in *C. procera* in the 1980s is correlated with a run of poorer wet seasons and with a period of increase in biomass of perennial grasses. However, causes of *C. procera* decline are unknown and experiments are needed on the longevity and competitive ability of this species.

Our results document a higher density of *Hakea arborescens*, *Eucalyptus pruinosa* and *Lysiphyllum cunninghamii* inside exclosures than outside, although these differences were generally not significant because of high variability and low replication. Despite lack of statistical significance, the data support reported increase in the density of trees in many areas throughout the Victoria River District in recent years (Kraatz 2000). It has been hypothesised that deeper plant available moisture, grazing, and fire suppression favour trees over grasses in savannas (Scholes and Archer 1997) and some experiments have supported this hypothesis (e.g. Walker and Langridge 1997). However, further experiments are needed to untangle the interactions of soil moisture and nutrients, and fire suppression and grazing, as causes of woody thickening.

Another interesting question is whether tree density will continue to increase in the Victoria River District, perhaps to the point where grass biomass significantly declines within pastures (Scanlan and Burrows 1990, Cafe *et al.* 1999). Fire experiments elsewhere on Kidman Springs and modelling studies indicate that woody thickening can be controlled by the strategic use of fire and grazing (Dyer *et al.* 1997, Dyer and Mott 1999, Liedloff *et al.* 2001). Other savanna studies suggest that periodic severe droughts also reduce tree densities (Fensham and Holman 1999).

Long-term studies such as this have an important role in documenting change in savanna vegetation as it occurs inside and outside exclosures and in demonstrating to pastoral managers the outcomes of conservative grazing compared with total exclusion of cattle. Further, the results of exclosure studies such as this can generate many questions (hypotheses). For example, what underlying processes have led to the substantial increase in perennial grass biomass in these tropical savannas? We speculate that increased soil moisture availability through litter accumulation and improving soil surface condition are important factors, but experimental data are needed to test this hypothesis. What grazing strategy in concert with wet-season rainfall will best maintain or improve future perennial grass vigour? What are the soil seedbank characteristics of woody plants, for example, *Hakea arborescens* is now well established at both sites, but by what means? As we learn more about these processes and causes of vegetation change, we can use them to better manage savannas to achieve desired production and conservation goals.

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