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Lessons from a 30 year burning experiment in northern Australian grazed tropical savannas

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Abstract

Like all savannas, the semi-arid tropical savannas of northern Australia have evolved with fire. However, the presence of fire in the landscape has changed significantly with the reduction of traditional Aboriginal burning and increased control of wildfires. The incidence of fire is now greatly reduced on most land used for grazing by livestock. To address concerns about how reduced fire might influence vegetation structure and productivity, a long term fire experiment at Victoria River Research Station, also known as Kidman Springs, 400km south of Darwin in the Northern Territory began in 1993. Treatments (each with two replicates) include: season of burning (early in the dry season in June, or late in the dry season in October); fire interval (two, four and six–yearly); and four unburnt controls. The treatments are applied on a calcarosol Eucalypt woodland and on a vertosol grassland. The three decades have seen unanticipated climate driven shifts in pasture composition, and increases in woody cover in all but the most intense fire regimes and subsequent declines during a recent run of drier years. Fire prevented woody cover increases since 2009 on the grassland. On the woodland woody cover fluctuated more through time, but was at similar or lower levels in 2023 to 2009, even on unburnt controls due to drought related dieback. The herbaceous understorey is resilient to fire with perennial grasses relatively unaffected and greater diversity post fire due to increases in ephemerals. Understorey herbaceous dry matter was only negatively correlated with woody cover on the grassland. Hence, concerns about increasing woody cover leading to reduced pasture productivity may be unfounded in the woodland, but without fire native woody encroachment into the productive grasslands can change the structure from a grassland to an open woodland and may negatively impact carrying capacity for livestock. Since 2013 wet season spelling has been implemented post fire. This has improved the pasture composition on the grassland and suggests the minimum required fire interval for effective management of woody cover could be increased from four to six yearly, provided fuel loads are adequate for an effective fire. Other research at the site has investigated biocrust, mite, faunal and above and below ground carbon storage response to long term fire regimes. This is the only long term grazed fire experiment in Australia's tropical savannas. It continues to provide new insights and is open to the global research community.

Introduction

Australian savannas are well adapted to fire but not grazing, having evolved with regular fire, but only very low levels of native herbivore pressure. The incidence of fire had greatly declined on grazed pastoral land compared to under Indigenous ownership and management due to cessation of traditional burning, reduced fuel loads due to grazing by introduced herbivores, and deliberate exclusion of fire by pastoralists to protect infrastructure and forage for livestock. There was evidence of woody encroachment into the most productive vertosol grasslands and concerns that continued lack of fire would lead to further woody encroachment and loss of carrying capacity for livestock due to competition between the woody and pasture layers. The Kidman Springs fire experiment started in 1993 and for thirty years has provided insights into the long-term impacts of regular fire regimes, and how fire can be managed in the grazed context. Combined with insights from long term grazing exclosures at the site (Bastin et al. 2003) the experiment can provide insights into the broader potential drivers of vegetation change (fire, rainfall, grazing, CO_2) in the region, answering questions that were not anticipated at its inception. This review aims to update the findings emerging from the site in the context of its beginnings.

Methods

The fire experiment is on Victoria River Research Station (VRRS) 400km south of Darwin in the Northern Territory on a calcarosol Eucalypt woodland and a vertosol grassland. 90% of the rain falls during the 'wet season' between November and March with distinct seasonally dry periods between June and October. On each site the following fire treatments (each with two replicates) include: season of burning (E-early in the dry season in June, or L-late in the dry season in October); fire interval (two, four and six–yearly); and four unburnt controls to give 16 160m x 160m plots separated by firebreaks. See Cowley et al. (2014) for full experimental design and methods. Since 2013, all plots have been rested from grazing post fire after the late dry season fires until the end of the following wet season, effectively providing a wet season spell every second year. In 2019 all two, four and six–yearly burn treatments were implemented. Tree basal area (TBA) and canopy cover were assessed using a bitterlich gauge at 19m intervals along 4 x 100m transects per 2.4 ha plot in 2009, 2017, 2019, 2021 and 2023. Total standing dry matter and species composition of the herbaceous understorey has been assessed annually from 1994 to 2001 and every two years thereafter. A linear mixed effects model in R was used to test the effect of burn interval and season of fire and for significant differences between burn treatments within year, and between years within treatments. The experiment-wise error rate was set at 0.05.

Results

The fire experiment began after an extended dry period with six of the seven years between 1986 and 1992 with below median rainfall (762mm). More recently four of the five years between 2018 and 2022 had below median rainfall (Fig. 1).

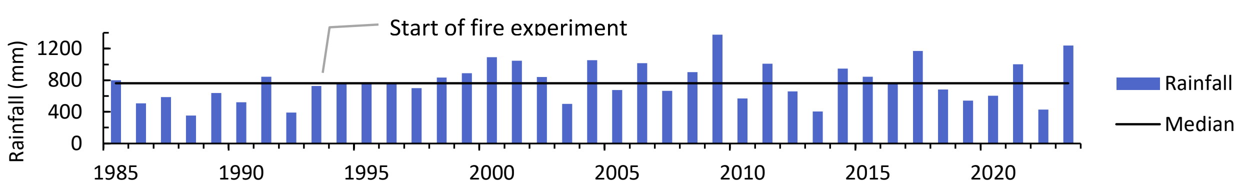

Figure 1. July to June rainfall and median rainfall (1970 - 2024) at VRRS

Pasture composition shifts in unburnt plots

Pasture composition varied through time even on unburnt controls, signalling grazing and rainfall responses. On the grassland *Iseilema* spp. declined from 19% in 1994 to 2% in 2023, while *Ophiurus exaltatus* increased from 0% to an average 18% of total yield since 2013 on the grassland control plots (Fig. 2). The proportion of *Aristida latifolia* increased at the expense of *Chrysopogon fallax* between 2003 and

2013 until the introduction of wet season spelling post burns. On the woodland the pasture shifted from arid shortgrass dominated to *Heteropogon contortus* dominated by 2001, although this subsequently declined following dry years between 2019 and 2021 (Fig. 2).

Woody cover

TBA significantly varied with year and burn interval on both the grassland (Fig. 3a) and woodland (Fig. 3b), while late dry season fires had significantly lower TBA than unburnt on the woodland, but not the grassland. The impact of 15 years of fire treatments had already influenced TBA when it was first measured in 2009, although differences were not significant. However, since then woody cover has further diverged between fire treatments, particularly on the grassland (Fig. 3a). TBA in 2023 on unburnt grassland plots was more than double 2009 levels, while TBA on the more severe fire regimes, early or late burnt every two or four years has stayed relatively stable since 2009. Late 2 had significantly lower TBA than unburnt in 2019 and 2023, and late 6 was lower than unburnt in 2023. On the woodland TBA peaked in 2019, except for the two most severe burn treatments late 2 and 4 yearly which did not vary through time. On the other woodland treatments TBA declined more with the dry years between 2019 and 2021 than on the grassland. Although by 2023 TBA was often comparable with levels in 2009, treatments had diverged enough that the unburnt woodland plots had higher TBA than all the late burnt plots and the 2 yearly early burnt treatment. The late 6 yearly burnt treatment went from having similar TBA to all other treatments in 2009 to having the lowest TBA by 2023.

In contrast to TBA, canopy cover varied significantly with treatment in all years on both the grassland and woodland. All late burnt plots and early 2 (except for the woodland in 2009) always had lower canopy cover than the unburnt plots in the woodland and grassland (Fig. 3c and 3d). Canopy cover was relatively stable on the grassland through time, except on the unburnt plots where it increased after 2009, while on the most severe burn treatment (late 2 yearly) canopy cover was lowest in 2023. Canopy cover peaked on the woodland in 2019 and was lowest in 2021.

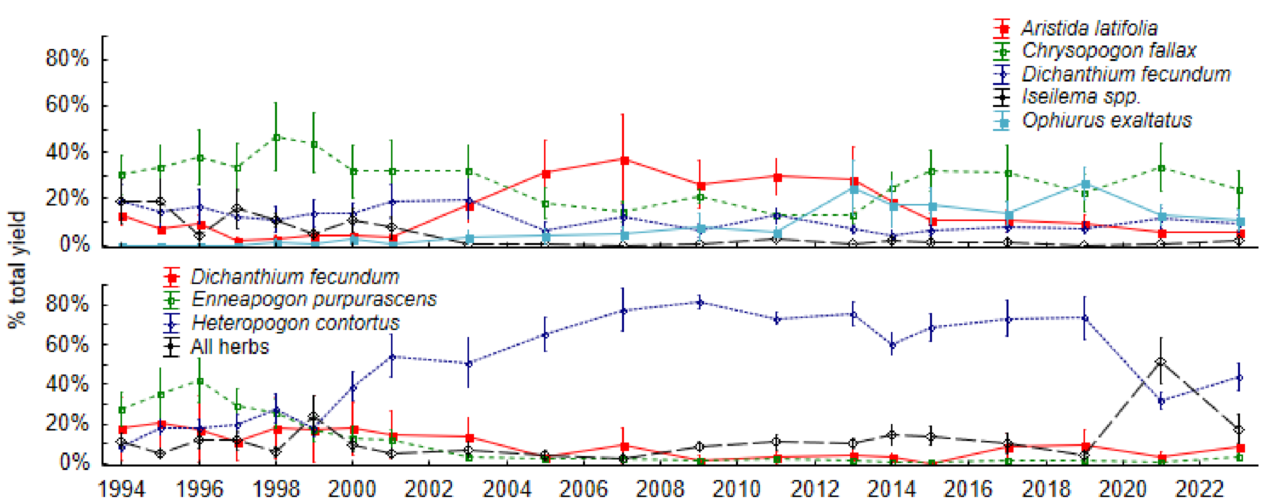

Figure 2. Change in species composition on unburnt control plots on the grassland (top) and woodland (bottom) savanna at VRRS. Mean +- the standard error

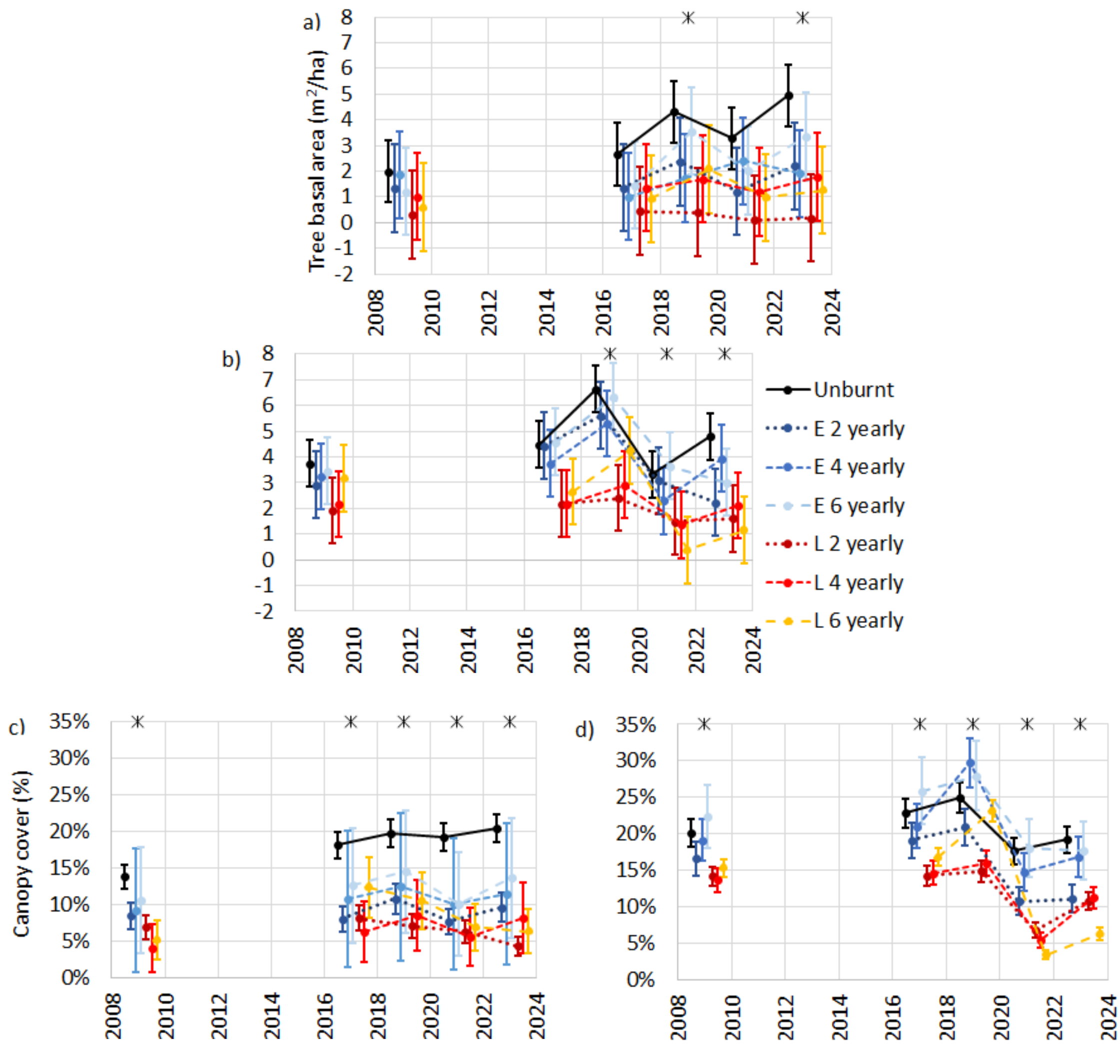

Figure 3. Tree basal area on a) grassland and b) woodland and canopy cover on a c) grassland and d) woodland through time for different fire treatments savanna at VRRS. Mean +- the 95% CI. * significant difference between treatments

Discussion

Cowley et al. (2014) hypothesized that the shift in composition of the woodland from arid short grass to *Heterogon contortus* was likely a response to multidecadal shifts in rainfall from drier prior to the fire experiment to wetter through the first two decades of the fire experiment. Similar increases had also been observed in grazed and ungrazed areas on the research station (Bastin et al. 2003). The subsequent decline in *H. contortus* during the recent drier years supports this. Similarly on the grassland, the replacement of the more arid adapted *Iseilema* spp with *Ophiurus exaltatus* which prefers damp conditions may also be in response to long term fluctuations in rainfall. A study of the full vegetation composition and diversity at the site in 2016 found the perennial grasses were unaffected by fire treatment, and vegetation diversity increased post fire with flushes in ephemerals (Lebbink et al. 2018).

Post fire spelling was introduced by fencing the fire experimental plots from the broader paddock in October 2013 to prevent high post fire grazing on the fire site which was contributing to a decline in pasture condition on more frequently burnt plots, particularly the early burnt plots (Cowley et al. 2014). Wet season spelling of the fire experimental plots for around six months every two years effectively reduces the average stocking rate by one quarter, compared to if continuously grazed at the same stocking rate. It also allows palatable species to establish and recover over the wet season in the absence of grazing. Within two years of wet season spelling, *Chrysopogon fallax* had recovered and *Aristida latifolia* declined to levels at the start of the experiment, although the recovery of *Dichanthium fecundum* has been much slower and has still not reached the same proportions as it was at the beginning the study on either soil type.

The impact of fire treatments on the woodland woody cover has also shifted since the introduction of post burning spelling. Before 2013 the 6 yearly and early burnt plots tended to have higher woody cover and lower fuel loads driving less effective fires. Cowley et al. (2014) concluded that fires need to be 4 yearly to manage woody cover. However, since 2013 even in dry years higher yields and more effective fires have contributed to declines in woody cover, particularly on the woodland 6 yearly late burnt plots. This suggests that provided fuel loads are suitable for effective fires, six yearly late fire may be sufficient to the manage the tree-grass balance on the woodland. On the grassland early and late 4 yearly fires were equally effective.

Although grassland woody plants were observed to be almost completely defoliated at times during the dry years, as of 2023 they had recovered to at least 2019 levels. Woody cover has remained relatively unchanged on the burnt grassland treatments, but may still be increasing on unburnt sites. This contrasts with the woodland site where declines in both TBA and canopy cover were greater and no treatments had recovered to 2019 levels by 2023. Following three dry years between 2018 and 2020 the combined impact of fire and dry years lead to the lowest canopy cover observed for the late and early 2 burn woodland treatments. Changes in canopy cover are more responsive to fluctuations in soil water deficits than tree basal area, because many of these species are semi-deciduous and regularly shed leaves in the dry season each year. Fire is more likely to cause topkill than mortality of these fire adapted species (Dyer 2001), which are exceptional resprouters. Loss of tree basal area represents woody plant death, whereas canopy cover can fluctuate rapidly without tree death. On the grassland burnt plots there are many small supressed shrubs of *Terminlia volucrens* and *Bauhinia lysiphyllum* which are vulnerable to top kill with fire. On the unburnt plots without regular fire, they have grown to trees > 2m in height, and exert competition with the understorey pasture layer (Cowley et al. 2021). In contrast there was less evidence of competition between the pasture and woody layers on the woodland, and drought led to significant tree deaths regardless of fire, as has been found previously in north eastern Australia (Fensham et al. 2019), suggesting fire could be prioritised to the more productive grasslands.

The fire experiment at VRRS continues to provide unique insights into the impacts of fire in the grazed context on the savanna vegetation, but also the less anticipated impacts of multidecadal shifts in rainfall on vegetation composition and structure. The site not only contributes to our understanding of savanna ecosystems, but also provides a visual demonstration of fire management for local land managers and has been used to determine the impact of fire on carbon storage, biodiversity and biocrusts.

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