

Influence of fire on the emergence of *Sarga intrans* seedlings in a north Australian tropical savanna

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Abstract

Fire is a very frequent and extensive event in the tropical savannas of northern Australia. It has the ability to either directly instigate seed germination by breaking dormancy, or modify the physical environment in a way that enhances seedling emergence from the soil seed bank. This study used a field sowing experiment to analyse the magnitude of *Sarga intrans* seedling emergence in different tropical savanna microsites and within different fire regimes of a manipulative fire experiment. Fire regimes were not a statistically significant factor overall in determining how many seedlings emerged in the field; biophysical factors such as canopy cover had a greater influence. At the start of the growing season 7 months after sowing, more seedlings emerged from areas away from the tree canopy than underneath it. In areas away from the tree canopy, and when seeds were sown on bare soil, the lowest number of seedlings emerged from unburnt plots. It is suggested that recent fire events remove competing vegetation, enhancing the number of seedlings that can emerge. However, having fire in the dry season before germination, rather than only in previous seasons, will result in some seed mortality and reduce the number of seedlings that later emerge. To some, *S. intrans* is regarded as a native weed where its distribution is thought to be expanding as a result of frequent fire. Leaving landscapes unburnt will limit the number of seedlings that emerge from the soil seed bank.

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Introduction

Tropical savanna is the dominant vegetation type in the northern third of Australia, characterised by a continuous, species rich layer of understorey plants (Stocker and Mott 1981). This grass layer has a propensity to burn in the winter dry season resulting from an annual cycle of fuel accumulation and desiccation (Cook 2003; Williams and others 2003c). As a consequence, fire is both frequent and extensive (Russell-Smith and others 1997; Gill and others 2000; Edwards and others 2001), and has a major influence on the floristic composition of grass layer vegetation (Bourliere 1983; Woinarski and others 2004).

Long-term (10-20 year) monitoring has shown a considerable difference in the abundance of grass layer species within frequently burnt and fire-excluded areas (Bowman *and others* 1988; Russell-Smith and others 2003; Woinarski and others 2004). Preferences for specific fire regimes can arise from changes to the number of new individuals that establish over time. When seed supply to an area is not limiting, differences in establishment are driven by the availability of microsites – physical features of the landscape suitable for germination and onward establishment (Eriksson and Ehrlén 1992; Zobel and others 2000; Setterfield 2002).

Microsites can be greatly modified by single fire events or longer-term fire regimes. Fire exclusion in tropical savannas typically leads to a greater mid-story stem density, increasing the depth of leaf litter on the soil surface and the level of shading (Hoare and others 1980; Williams and others 2003b). Litter abundance affects seedling establishment, with litter either preventing seeds from entering the soil seed bank, or inhibiting seedling emergence (Hamrick and Lee 1987; Fowler 1988; Facelli and Pickett 1991). Tolerance of canopy shading can be highly variable between grass genera, but is more likely to affect longer-term establishment rather than seedling emergence (Klink and Joly 1989).

Vegetation within the grass layer is removed by fire, so that in recently burnt landscapes, reduced inter-specific competition may increase the number of seedlings able to establish (Cook and others 1996; Williams and others 2005). Alternatively, the loss of vegetative cover could increase soil moisture evaporation, and lead to lower rates of germination and seedling survival (Mott and others 1976). Higher rates of seedling establishment may occur directly as a result of fire, rather than indirectly through modifications to microsites. Soil-stored seeds can be released from dormancy after exposure to heat or smoke from fire, particularly after higher intensity fires that occur later in the dry season (Auld and O'Connell 1991; Auld and Bradstock 1995; Campbell and others 1996; Williams and others 2003a and 2004).

Sarga intrans (F.Muell) Spangler (synonym: *Sorghum intrans* F.Muell.; taxonomy follows Spangler 2003) is a tall annual grass that often contributes the majority of ground fuel in tropical savanna habitats of the Northern Territory (Williams and others 2003c). Whilst several years of

fire exclusion appear to be correlated to a decrease in the abundance of this species (Fensham 1990; Russell-Smith and others 2003), anecdotal evidence suggests repeated burning has expanded its distribution (Miles 2003). For *Sarga timorensis* Kunth (synonym: *Sorghum ecarinatum* Lazarides) in sandstone heath, abundance is significantly higher after fire (Russell-Smith and others 2002). *Sarga intrans* is considered by some to be a native weed and generates strong debate given its supposed ability to fuel higher intensity fires (Miles 2003). As yet though, manipulative fire experiments have not been performed to document whether fire has an influence, either directly or indirectly through habitat modifications, on *S. intrans* emergence and subsequent abundance. The present study used a field seed sowing experiment to quantify the influence of short-term fire regimes on the ability of *S. intrans* seedlings to emerge as small seedlings in a range of tropical savanna microsites.

Methods

Study site

Field studies were performed at Berry Springs, 40 km southeast of Darwin in the Northern Territory of Australia (12° 41' 51.53" S, 130° 58' 53.22" E). The site is located within an undisturbed section of a Wildlife Zoo which has been surrounded by a 3 m high predator exclusion fence since its opening in 1989. No cattle have grazed inside the Zoo area during this time, although agile wallabies (*Macropus agilis*) occur at a much higher density than normal (J Hendersen, *pers. comm.*). The region's climate is monsoonal; consistently warm with most of the annual rainfall (1402 mm at Middle Point, 35 km from the study site) falling in the wet season between October and March. Soils are well drained or moderately well drained (*sensu* McDonald and others 1990), dominated by gravely red earths with extensive outcrops of laterite in the north of the study site, and earthy sands in the southern end (Christian and others 1953).

The site is within a tropical savanna open forest (*sensu* Specht and others 1995) with a *Eucalyptus tetradonta* / *Eucalyptus miniata* tree canopy. A continuous and species rich ground layer of grasses, sedges and forbs is present in all but the most shaded of areas under a dense tree canopy. The study species, *S. intrans*, is not present within the study site, but is abundant on the other side of the Zoo's fence and probably existed at the study site in the 1980's and 1990's (J Hendersen *pers. comm.*; Sivertsen and others 1980).

Seed fall of *S. intrans* occurs in the late wet season (late March – early April) before the last of the rain showers, so that their hygroscopic awn will bury the seed in the soil for the duration of the dry season (Andrew and Mott 1983). Seeds remain buried and dormant throughout the dry season, and germinate synchronously in response to the first significant (10-15 mm) rain showers of the early wet season (October – November; Andrew and Mott 1983). Any seed that has not germinated in this period will not be viable and therefore does not form part of the soil seed bank

in the next year (Andrew and Mott 1983).

Experimental approach

Fire regimes

A seed sowing experiment was undertaken in the dry season of 2006 and subsequent wet season of 2006-2007. It used experimental compartments where fire regime treatments were being applied for a larger study into the effects of fire on biodiversity in northern Australia. For that study, a north-south line of 18 experimental compartments (1 ha; 80 m x 125 m) were established, separated by 3 m wide slashed firebreaks. A randomised complete block design allocated six fire regimes to three random compartments each. The present study used just three of these fire regimes: annual early dry season burning (commencing in 2004; hereafter known as 'burnt'), biennial early dry season burning (commencing in 2005; hereafter known as 'previously burnt'), and no burning / control (hereafter known as 'unburnt'). The 'burnt' regime therefore experienced a fire in the study year and the year before, the 'previously burnt' regime experienced a fire in the year before the study but not during, and the unburnt regime experienced no fires. The mean fuel load at the study site immediately prior to burning in the study year (June 2006) was estimated at 2 t ha⁻¹, and the mean fire intensity of all three experimental compartments was approximately 130 kW m⁻¹ (RJ Williams, unpublished data).

Field sowing experiment

The field sowing experiment comprised a nested 5-way ANOVA design consisting of the following fixed factors: fire regime (3 levels), canopy cover (2 levels), and litter treatment (2 levels), and the following random factors: block (3 levels) and plot (2 levels). The two canopy cover treatments consisted of being either directly under the tree canopy (mean canopy cover of c. 85 percent), or within tree canopy gaps (mean canopy cover of c. 30 percent), as measured by a forestry densiometer (Lemmon 1956). Canopy cover was measured periodically throughout the year and did not change noticeably between seasons or after fire. The two litter treatments comprised either sowing seeds on a 5 cm layer of dead, locally-sourced leaf litter (100 percent cover; litter added if necessary) or on bare soil (existing litter removed). Standing biomass in the grass layer was left intact.

Seeds were sown into square 1 m² quadrats constructed using weldmesh (50 mm aperture size, 2 mm gage), cut into 1 m x 100 mm sections and held together with wire joiners. Sections were cut so that the metal spikes on the weldmesh would allow it to enter the soil up to a height of 50 mm, leaving another 50 mm for an aboveground fence. Strips of fire-proof flywire were laid on the soil before metal sections were pushed into the soil, allowing the flywire to stand upright next to the metal fence and prevent horizontal seed movement either in or out of the quadrat. Seeds were collected in late March 2006, 8 km from the study site, and sown in early April at a density of 250 seeds per quadrat.

Seedling density in each quadrat was counted non-destructively in early December immediately after the main germination period in November (Andrew and Mott 1983). Differences between seedling density were analysed with untransformed count data in a nested 5-way ANOVA in *Statistica 5*, and displayed graphically as percent germination.

Results

Spatial variability in seedling emergence

Between 0.8 and 42.8 percent (mean = 18 percent) of the 250 sown seeds per quadrat had established as small seedlings (10-20 cm) by early December. In effect, seeds of *S. intrans* were able to emerge as seedlings in all microsites of this tropical savanna site. The ANOVA indicated a strong influence of the spatial variable 'block' on the number of seedlings that had germinated by December (MS effect = 6969.160; *table 1*). Indeed both 'block' and 'plot' showed a significant effect overall on seedling density (*table 1*). Field observations support this; the number of seedlings that emerged appeared highly variable at the quadrat level along the 1.8 km site, irrespective of treatments imposed.

Effect of canopy cover

Of the two biophysical variables, 'canopy cover' and 'litter treatment', only 'canopy cover' showed a significant effect overall on seedling density ($F_{1,6} = 9.814$, $p = 0.0203$; *table 1*). With all fire regimes and litter treatments combined, c. 15 percent of seeds had emerged under a closed canopy, compared to c. 20 percent in open canopy areas.

Differences among fire regimes

There was no significant effect of 'fire regime' overall on seedling density ($F_{2,6} = 0.107$, $p = 0.9003$; *table 1*), but a significant interaction resulted between 'fire regime' and 'canopy cover' given that the significant affect of 'canopy cover' overall was not consistent within all the three fire regimes. Similarly, there was a significant interaction between 'canopy cover' and 'litter treatment' (*table 1*), and a significant 3-way interaction resulted between 'fire regime', 'canopy cover' and 'litter treatment' (*table 1*).

Despite no significant effect of fire regime overall on the density of seedlings that had emerged, there was one particular combination of canopy cover and litter treatments – an open canopy where seeds were sown on bare soil – that showed a significant difference in seedling density among the three fire regimes ($F_{2,33} = 6.763$, $p = 0.0035$; *fig. 1*). For seeds sown under these conditions, significantly more seedlings germinated in the 'previously burnt' regime than any other regime. Quadrats in this fire regime had, on average, 12 percent more seedlings than in the 'burnt' regime, and 16 percent more seedlings than in the 'unburnt' regime (*fig. 1*). For all other combinations of 'canopy cover' and 'litter treatment', there was no difference in the density of seedlings among fire regimes (*fig. 1*).

Table 1 - ANOVA summary table including all treatment factors, and all statistically significant 2- and 3-way interactions. Treatment variables significant at the 0.05 level are identified with an asterisk and bold type.

Treatment variable/s	MS Effect	F	P
Fire regime	744.771	F _(2,6) = 0.107	0.9003
Block*	6969.160	F _(6,9) = 10.427	0.0013*
Canopy cover*	6110.028	F _(1,6) = 9.8141	0.0203*
Plot*	668.389	F _(9,72) = 2.164	0.0346*
Litter	1236.695	F _(1,6) = 378.826	0.1208
Fire regime x canopy cover*	4165.632	F _(2,6) = 6.691	0.0297*
Canopy cover x litter treatment*	2288.028	F _(1,6) = 27.088	0.0020*
Fire regime x canopy cover x litter treatment*	2126.715	F _(2,6) = 25.179	0.0012*

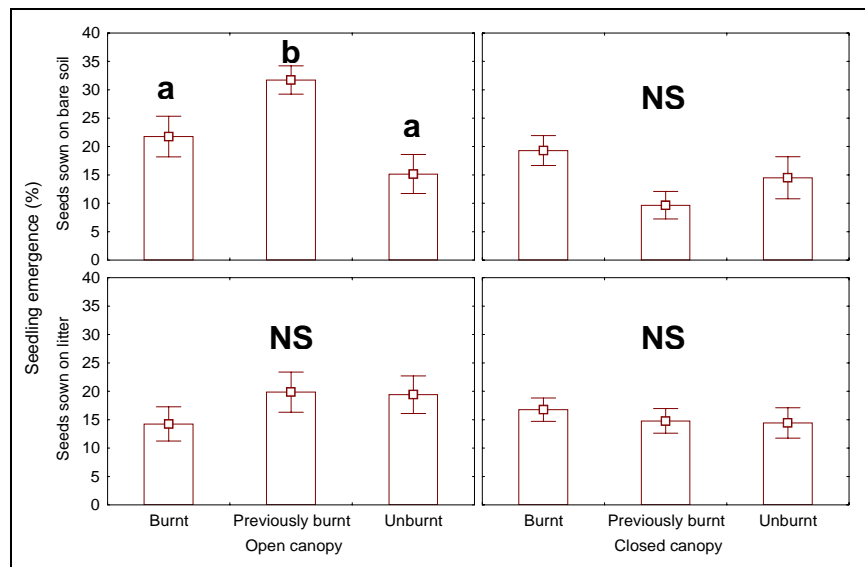


Figure 1 - Seedling emergence (%) within each fire regime, for each combination of canopy cover and litter treatment. Values are the mean \pm 1 SE. Columns with different letters are statistically significant ($P < 0.05$) within the particular combination of canopy cover and litter treatment.

Discussion

Spatial variability in seedling emergence

The high degree of spatial variability (highlighted by the significant overall effect of ‘block’ and ‘plot’; *table 1*) could be indicative of unintentional within-treatment differences between blocks. Blocks at the southern end of the site have a much greater mid-storey stem density, so quadrats there in the ‘open canopy’ treatment are generally shaded more often during the day, have a higher canopy cover than the site mean, and block more light for a given canopy cover value. Blocks in this area, as a consequence of the greater mid-storey stem density, also had a greater amount of litter present on the ground surface

during sowing, and falling in the quadrats during the study (K Scott, unpublished data).

Alternatively, there may be other site factors, not tested for in this study, that affect *S. intrans* establishment inconsistently throughout the site. A large agile wallaby (*Marcopus agilis*) population is enclosed by a tall fence within the site area, but they do not appear to graze the site uniformly. Seedlings with signs of grazing and subsequent death were only found within the dense mid-storey area at the southern end of the site and more often in tree canopy areas, the preferred habitat for Agile Wallabies avoiding heat stress during the day (Menkhorst and Knight 2001; Stirrat 2004). Grass layer vegetation was not removed in each quadrat and is far from being uniform among treatment quadrats (K Scott, unpublished data). Differences in the density of competing vegetation could be enough to influence the number of seedlings that establish (Cook and others 1996; Williams and others 2005). Lastly, noteworthy differences in soil moisture occur throughout the site during the germination period (November; K Scott, unpublished data), such that drier, sandier soils at the southern end of the site may have allowed seedlings to desiccate and die at a greater rate than other soil types (Andrew and Mott 1983; Andrew 1986).

Effect of canopy cover

A significantly lower number of *S. intrans* seedlings emerged in closed canopy areas, showing much similarity to the establishment preferences of the grasses *Sarga timorensis* (synonym: *Sorghum brachypodium*; Cook and others 1996) and *Andropogon gayanus* Kunth (Setterfield and others 2005) in the same region. The benefits of less competing vegetation in these closed canopy areas (K Scott, *pers. obs.*) is therefore seemingly outweighed by the detrimental effects of high amounts of naturally accumulating litter providing a barrier to seedling emergence (Lamont and others 1993; Hoffmann 1996), or the higher grazing intensity by agile wallabies. A higher density of mature *S. intrans* plants is often noted within canopy gaps and is likely to be, in part at least, a consequence of this emergence preference (Lane 1996).

Differences among fire regimes

The lack of a significant effect of 'fire regime' overall is not consistent with the marked increase in abundance of the annual *S. timorensis* (synonym: *S. ecarinatum*) after fire in a sandstone heath (Russell-Smith and others 2002). This contrast could reflect differences in the two species, or the differences in canopy cover between the two different vegetation types, especially given the significant 'fire regime' x 'canopy cover' interaction in the present study (*table 1*). Only one combination of 'canopy cover' and 'litter treatment' resulted in a significantly different number of seedlings between fire regimes (closed canopy, seeds sown on bare soil; *fig. 1*). That such a fire-effect was only evident in this treatment combination may reflect the higher fuel loads in these areas, and consequently higher fire intensities providing the strongest contrast between burnt and unburnt compartments.

Within the open canopy areas and when seeds were sown on bare soil, the highest number of seedlings emerged in burnt compartments (*fig. 1*), which could be related to the benefits of removing competing vegetation. The emergence of sown *S. timorensis* seeds was found to be lower in the presence of perennial grasses (Cook and others 1996), and total seedling density is known to be higher when grass layer vegetation is removed, irrespective of fire (Williams and others 2005).

The density of seedlings in the 'burnt' regime was 12 percent lower than the 'previously burnt' regime, indicating that fire in the study year was somewhat deleterious, but still better than having no fire (*fig. 1*). This lower seedling density in the 'burnt' regime can be attributed to seed mortality during fire (Andrew and Mott 1983; Watkinson and others 1989). While it was not observed in the field, seeds can die after breaking dormancy during fire, germinating in dry season rainfall events, and then not having adequate access to soil moisture (Andrew and Mott 1983).

Given that the lowest number of seedlings emerged from the unburnt compartments (when sown under an open canopy and on bare soil; *fig. 1*), leaving landscapes unburnt if possible may be a desirable management option if wanting to decrease the abundance of *S. intrans*.

Conclusion

This study has shown that fire in itself does not have a major short-term influence on the emergence patterns of *S. intrans* seedlings in the tropical savannas of northern Australia. Rather, we confirm the much stronger influence of biophysical factors such as canopy cover. At least in open areas, where seeds fall on bare ground, leaving the landscape unburnt will lessen the number of seedlings that emerge from the soil seed bank. This would be advantageous if aspiring to reduce the abundance of the species. Further work is being undertaken to explore the influence of the treatments on other variables, such as end-of-season establishment and seed production, and the influence of litter on seedling emergence in shade house trials.

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