Incentivising fire management in Pindan (Acacia shrubland): A proposed fuel type for Australia's Savanna burning greenhouse gas emissions abatement methodology

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Incentivising fire management in Pindan (Acacia shrubland): A proposed fuel type for Australia's Savanna burning greenhouse gas emissions abatement methodology

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Summary The Australian Government has sanctioned development of greenhouse gas emissions (GHG) abatement methodologies to meet international emissions reduction obligations. Savanna burning emissions abatement methodologies have been available since 2012, and there are currently 72 registered projects covering approximately 32 million ha. Abatement to date has exceeded 4 million tonnes of carbon dioxide equivalent (CO2-e) principally through the application of low intensity early dry season fire management to reduce the amount of biomass combusted in higher intensity late dry season (LDS) fires. Savanna burning projects can only be conducted on areas with eligible fire-prone vegetation fuel types where implementing the improved fire management regime is considered ecologically appropriate. This study assesses the suitability of including tall *Acacia* shrublands ('Pindan') as a new eligible fuel type. These shrublands make up 12% (~2 million ha) of the Kimberley region, Western Australia, where, on average, 32% is fire affected annually, mostly in the LDS. A standard assessment protocol was applied to describe vegetation fuel type structural and pyrolysis characteristics. We show that Pindan (i) can be identified and mapped as a unique tall *Acacia* shrubland vegetation fuel type, (ii) characterised by a significantly greater shrubby fuel load biomass, and (iii) the conservation status of which would benefit from imposition of strategic prescribed burning programme. Savanna burning projects in the Pindan fuel type could potentially abate up to 24.43 t.CO_2-e/km^2 per year, generating significant income and employment opportunities for predominantly Indigenous land managers in the region.

Key words: *Acacia*, fire, fuel, greenhouse gas emissions abatement, Pindan, Savanna, Shrubland, vegetation.

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Introduction

Considerable steps have been taken in recent years to develop carbon farming methodologies to incentivise and provide formal accounting frameworks for the reduction of greenhouse gas (GHG) emissions from fire-prone north Australian Savanna landscapes. Currently, 'Savanna burning emissions abatement' methodologies apply to Savanna regions occupying 483 000 km^2 in the high rainfall zone (HRZ; >1000 mm mean annual rainfall), and 706 000 km^2 in the low rainfall zone (LRZ; 1000–600 mm mean annual rainfall) (Fig. 1) (Australian Government 2015). Reduction in GHG emissions is achieved through implementing strategic prescribed burning utilising low intensity fires, principally in the early dry season (EDS—before August), to effectively manage the risk of potentially extensive, typically intense wildfires occurring in the late dry season (LDS – from August 1st onwards) (Russell-Smith *et al.* 2009b; Whitehead *et al.* 2014).

As at June 2018, there are 72 formally registered Savanna burning projects (Australian Government 2018). Each tonne of carbon dioxide equivalent (CO_2-e) abated earns one Australian Carbon Credit Unit and can be traded on regulated or voluntary markets. Savanna burning projects offer economic diversification opportunities for pastoral enterprises, Indigenous land managers and the formal conservation estate (National Parks, Indigenous Protected Areas) (Walton *et al.* 2014), as well as a variety of significant environmental, social and cultural benefits (Russell-Smith *et al.* 2013, 2015b; Robinson *et al.* 2016). In future, it is likely that additional Savanna burning methodologies will become available, based on carbon sequestration through longer-term accumulation of coarse woody debris (Cook *et al.* 2015), increasing living tree biomass (Murphy *et al.* 2010) and possibly maintaining top-soil pools (Bray *et al.* 2016). The technical feasibility of similar fire-mediated abatement and sequestration accounting methods in arid rangelands has been demonstrated but requires further development (Burrows 2014).

Registered Savanna burning projects can be conducted only on eligible 'Vegetation Fuel Types' (VFTs) of which there are a total of nine, including five in the LRZ (Australian Government 2015; Lynch *et al.* 2015). Eligible VFTs include typical

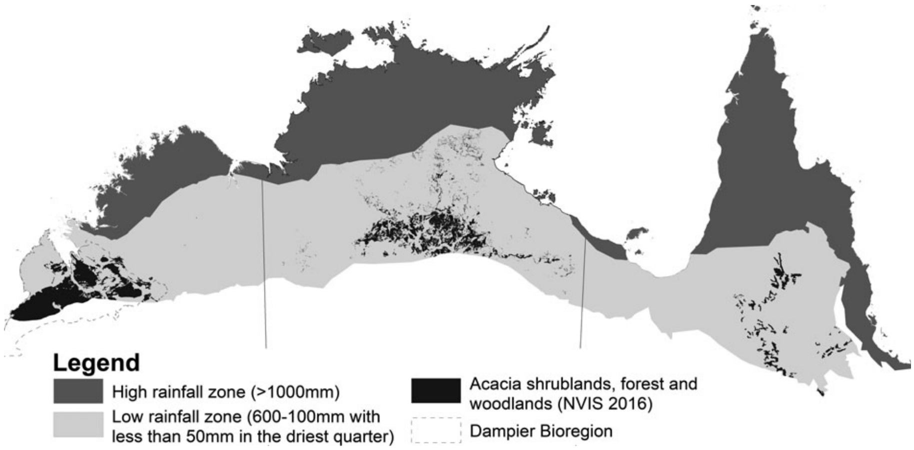

Figure 1. Extent of *Acacia* communities (NVIS Version 4.1) in the low rainfall zone. Grey shading indicates high and low rainfall zones as per 2015 Emissions Abatement through Savanna Fire Management Determination (Australian Government 2015).

tussock and hummock (*Triodia* spp.) grasses and litter associated with Savanna woodlands and open-forests. Ineligible fuel types include a variety of habitats where implementing EDS prescribed Savanna burning methods are ecologically inappropriate, for example, relatively dense-canopied, fire-sensitive Lancewood (*Acacia shirleyi*) and Bullwaddy (*Macropteranthes keckwickii*) thickets (Woinarski & Fisher 1995; Russell-Smith *et al.* 2010); and fertile, pastorally productive open-woodlands and grasslands where EDS fire management would very likely result in significant woody thickening and encroachment (Cowley *et al.* 2014; Russell-Smith *et al.* 2014).

This study assesses the potential for adding a tenth VFT; fire-prone, Pindan tall (>2 m) *Acacia* shrubland. Shrubland associations situated on the red sandy plains in the western LRZ of WA (Fig. 1) are commonly called 'Pindan' (Speck *et al.* 1960; Kenneally *et al.* 1996; Payne & Schoknecht 2011; Beard *et al.* 2013). Kenneally *et al.* (1996) describes Pindan on the Dampier Peninsula as a wooded grassland with a sparse upper layer composed mainly of eucalypts with a dense, often thicket-forming, middle layer predominantly of wattles. Typically, this wattle layer or shrubland varies in height and density depending on fire regime dynamics. Postfire recovery of the mature shrub stratum following intense fires typically takes 4–5 years (Radford & Fairman 2015), or 5–7 years (Kenneally *et al.* 1996).

As stipulated in the formal Savanna burning methodology (Australian Government 2015), inclusion of Pindan tall *Acacia* shrublands as a separate eligible VFT requires demonstration that (i) these areas are spatially distinct; (ii) exhibit unique fuel, fire behaviour or pyrolysis characteristics that distinguish it from other eligible VFTs, and; (iii) GHG emissions from fires occurring in the new class can be effectively reduced, and ecologically sustainably managed, through the undertaking of strategic prescribed EDS fire management activities. In this study, we address each of these requirements by characterising the components required to calculate GHGs, assessing their uniqueness against existing VFTs and discussing associated ecological and community benefits that could be derived from financially incentivised fire management.

Methods

Study area

Rainfall and temperature conditions across the extent of Pindan are highly monsoonal, with rainfall occurring mostly in the wet season months November to April (Fig. 2a). Mean annual rainfall in the region ranges from 962 mm recorded at Country Downs, to 516 mm at Bidyadanga (source: www.bom.gov.au). The wet season (rain year) mean total rainfall is highly variable between years and across the region (Fig. 2b). Annual temperature at Derby, a typical LRZ weather station, ranges from a mean maximum 37.2°C in the wet season (December) to a mean minimum of 14.8°C in the dry season (July) (source: www.bom.gov.au/climate/data).

As for Australia's northern Savannas generally, these seasonal conditions progressively promote the occurrence of fires over the 7-month dry season as fuels cure and LDS fire-climate conditions become more severe. For the 184 800 km^2 Kimberley LRZ region, an annual mean of 32% was burnt over the period 2000–2017, with the majority (63%) occurring in the LDS period (source: www.nafi.org.au) (Fig. 3a).

Pindan distribution and fire history mapping

The distribution of Pindan '*Acacia* shrublands' was derived using VFT mapping methods as outlined in Lynch *et al.* (2015) (see Methods details). Mapping was based on EDS 2017 Landsat 8 imagery (NASA http://glovis.usgs.gov/), and the final map was produced in accordance with VFT mapping requirements (Australian Government 2015).

The regional fire history was assessed for the years 2000–2017 in a Geographic Information System using a monthly/annual burnt area archive derived from MODIS satellite data (250 m pixel; source: www.nafi.org.au) (Fig. 3a).

Field sampling

Greenhouse gas emissions from Savanna fires are a product of the mass of available fuels combusted during a fire, and the emission factors of accountable GHGs, methane and nitrous oxide (Russell-Smith *et al.* 2009a, 2015a). The mass of fuel consumed is a product of three elements: the area burnt; the mass of fuel load accumulated (FLA); and the proportion of the fuel exposed to fire that is combusted (the burning efficiency factor, BEF). The fuel load considers the combustible fuel components: grass and

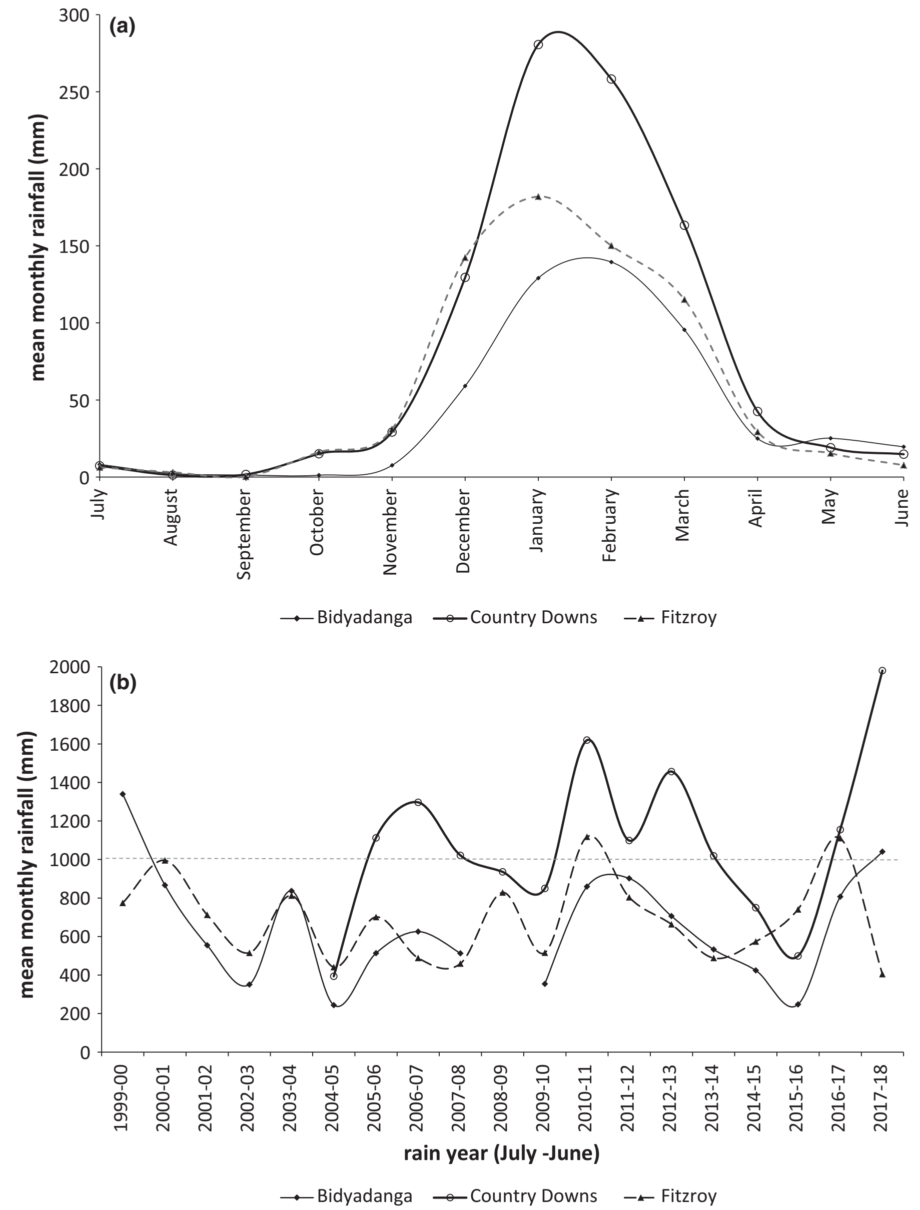

Figure 2. (a) Mean monthly rainfall distribution for three weather stations in the study area (source: www.bom.gov.au). (b). Mean annual rain-year (one wet season, July–December–June) rainfall distribution 2000–2018 (source: www.bom.gov.au)

litter (fine fuel), twigs (coarse fuel <6 mm dia.), logs (heavy fuel >5 cm dia.) and shrubs (standing woody fuel <5 cm diameter at breast height [DBH]). FLA for respective components can be estimated relative to time-since-last-fire (TSF), and postfire estimates calculated based on the proportional consumption of fuel components and accounting for burnt area patchiness. Emission factors were derived from previous representative studies (Meyer & Cook 2015). The methods for data collection, and subsequent analyses, follow Russell-Smith *et al.* (2009*b*) and Murphy *et al.* (2015) (see Methods details).

Field observations to measure pre- and postfire fuel loads and consumption were undertaken covering a range of fuel ages, in the EDS, April 2016 and June 2017, and in the LDS, August 2016, August and November 2017. In total, 102 prefire assessment plots (100 m transects) were established, 59 in the EDS and 43 in the LDS (Fig. 3).

Data analysis

Data were analysed following procedures outlined in Yates *et al.* (2015) (see Methods details). FLA relationships for respective fuel components were derived with TSF using linear regression; where significant these were used to estimate fuel loads at annual time steps up to a maximum of 10 years.

Seasonal litter fall is typically observed to be greater in woody Savannas in the LDS, resulting in larger LDS fuel litter loads (Cook 2003; Cuff & Brocklehurst 2015). Although it is likely that tall *Acacia* shrubland litter fuels likewise increase in the LDS, in the absence of available litter fall data we make no allowance for differences in seasonal litter fuel loads.

Postfire consumption of each fuel component, fire patchiness and resultant BEF (accounting for the proportion of fuel combusted by fire and patchiness) were derived for EDS and LDS fires, respectively, of low, moderate and high severity (Yates *et al.* 2015).

Results

Pindan distribution and contemporary fire history

Figure 1 shows the extent of shrublands across the LRZ according to national vegetation mapping (NVIS Ver.4.1, Australian Government, Department of Environment and Energy, Australia). Figure 3b shows vegetation fuel type mapping (this study) across the Dampier bioregion (Thackway & Cresswell 1995) where Pindan shrublands extend onto the Dampier Peninsula and comprise 12% of the Kimberley LRZ, covering 23 189 km^2. Over the period 2000–2017, an annual mean of 37% of the mapped Pindan shrublands area was burnt, of which most (72%) occurred in the LDS period. Assessment of the fire frequency over the same period indicated that 40% of Pindan was burnt at frequencies 0.45 or greater (i.e. 8 or more times) (Fig. 4a). Year-to-year variability in fire extent is high (Fig. 4b). In the 3 years

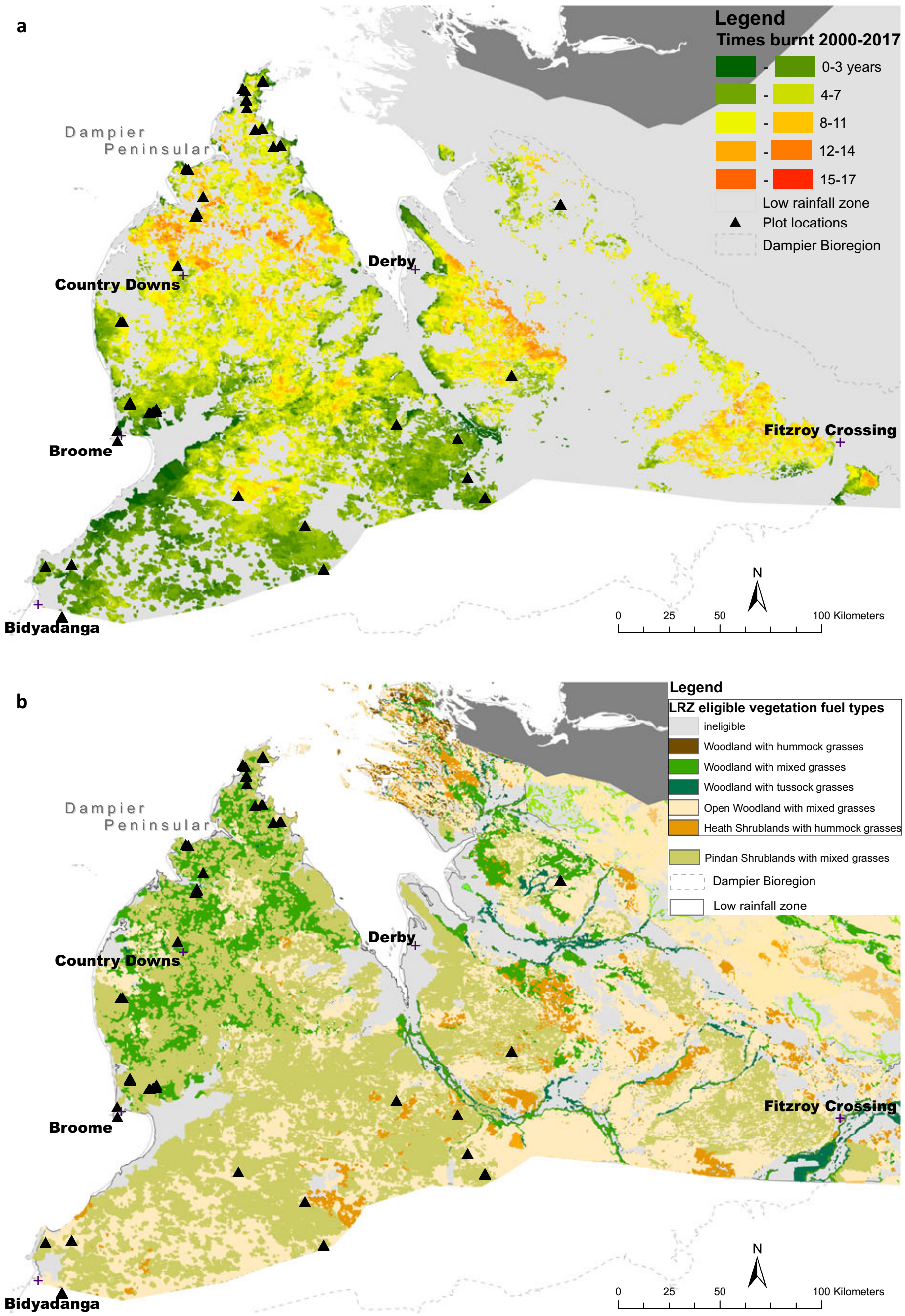

Figure 3. (a) Fire frequency over years 2000–2017 (source:www.nafi.org.au) in Pindan shrublands. (b) Distribution of Pindan *Acacia* shrublands in the Low rainfall zone. Field plots are black triangles.

prior to field sampling (2013–2015), at least half (62%, 50% and 52%, respectively) of the Pindan area was burnt, most extensively in the LDS (Fig. 4b). Over these 3 years, 15% of the area of Pindan was burnt in consecutive years, and <1% remained unburnt over this period. Notably, in both 2016 and 2017, just 10% of Pindan was burnt.

Field observations

Plots were characterised as *Acacia* shrublands, dominated by Broome Pindan Wattle (*Acacia eriopoda)* and Wongai Wattle *(A. tumida),* with lesser representation of *A. colei, A. monticola* or *A. platycarpa*. The average height of mature *Acacia* (woody stems > 5 cm DBH) was 5.4 m (SD = 1.2). Emergent trees were present in 90% of the plots at a mean height of 10.3 m (SD = 1.7), and commonly included bloodwoods (*Corymbia dampieri, Corymbia zygophylla, Corymbia polycarpa*) and *Eucalyptus* species. The ground stratum was dominated by tussock grasses in higher rainfall areas, with increasing contributions of hummock grasses down the rainfall gradient. Refer to Supporting Information for further detail.

Prefire assessments

One hundred and two FLA plots were assessed and of these 78% had been burnt within the preceding 5 years. The highest proportion (27%) of plots were 2 years unburnt; a consequence of the extensive 2015 fires. The median total fuel load of 13.82 t/ha was largely comprised of fine fuel (41%) and woody shrub (36%) components. Fine fuels mostly comprised litter (67%). The grass to litter ratio was observed to increase for up to 5 years TSF, after which it decreased as the litter continued to accumulate (Fig. 5). Radford and Fairman (2015) previously also noted that, as Pindan shrubland (dominated by *Acacia tumida*) canopy developed with increasing TSF, there was associated loss of perennial and annual grass biomass after 5 years.

Fine fuel accumulation exhibited a significant relationship with TSF (Fig. 6), albeit with a low R^2 ($R^2 = 0.2$, $P < 0.0001$, SE = 0.6); no significant relationships were observed with accumulation of coarse and heavy fuels. A significant relationship was observed for shrub fuels FLA ($R^2 = 0.1$, $P < 0.005$, SE = 0.8), attributable to shrubs >2 m, comprising ~80% of the shrub fuel load in all years TSF. Compared to eligible LRZ vegetation fuel classes, the contribution of shrub fuels in the tall *Acacia* shrubland samples 5 years after fire was 2.8 times that of Woodland with Hummock grass (WHu), and 18.8 times that of Woodland with Tussock grass understorey (WTu) (Yates *et al.* 2015). The proportions of stem and leaf components in shrub biomass measurements were typical of those described for other fuel types (Yates *et al.* 2015). Live shrub densities showed no strong relationships with TSF and no significant relationships were observed for dead shrub densities. Except for tall shrub biomass accumulation relationships (Fig. 7), above observations generally reflect fuel accumulation relationships observed similarly in other eligible LRZ fuel types – where only fine fuel accumulation was observed to be significantly related to TSF (Yates *et al.* 2015).

Three long-unburnt (10+ years; refer Fig. 6) plots exhibited very high fine fuel loads (mean 19.1 t/ha), five times the median (4.14 t/ha). Such long unburnt areas are rare given the prevailing regional fire regime, occurring only as very small areas (approximately 1 ha) in either highly managed situations (road reserves, house blocks), or in isolated fire-protected pockets.

Postfire assessment

Postfire measurements reported here were made at 38 of the 102 prefire assessment plots. Not all postfire treatments were implemented (i.e., burnt and subsequently re-measured) because of operational concerns in carrying out fire treatments particularly in the LDS.

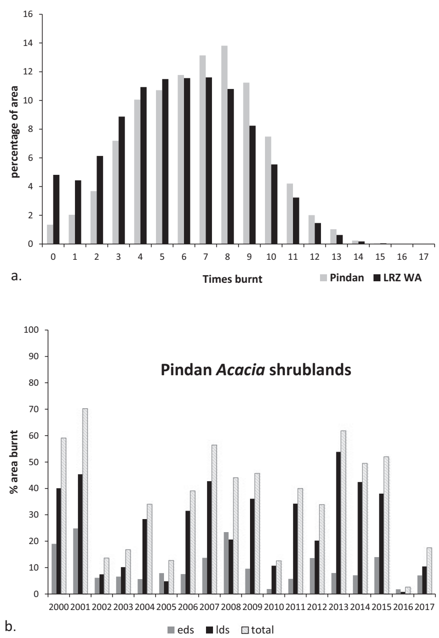

Figure 4. Fire regime in mapped Pindan for the period 2000–2017: (a) fire frequency in Pindan and low rainfall zone (LRZ) of WA; (b) percentage of area of Pindan burnt annually in early dry season (EDS), late dry season (LDS) and total.

Fire patchiness data were collected from 38 postfire treatments plots, plus an additional 11.7 km (i.e. 117 × 100 m sections) from recent fires in the study area. Patchiness decreased as per cent area burnt increased by 12.3% in the LDS (Table 1). In the EDS, 44% of fires were of low severity and 56% of moderate severity. In the LDS, 11% were of low severity, 55% of moderate severity and 34% of high severity.

The consumption of fine, coarse, shrub and heavy fuels with respect to fire severity was comparable with other VFTs (Yates *et al.* 2015). BEF were calculated by combining consumption and burnt patchiness data, and assuming residual ash of 3.8% based on extensive studies for LRZ VFTs reported by Yates *et al.* (2015) (Table 1). Reported observations were generally congruent with equivalent data for other LRZ VFTs, with the notable exception that EDS and LDS BEFs for coarse fuels in tall *Acacia* shrubland samples were around 10% more than for other LRZ VFTs (Table 1). Seasonal CH_4 and N_2O emission factors for respective fuel components were applied as per Meyer and Cook (2015).

Discussion

The primary motivation for undertaking this assessment was to evaluate the potential for including Pindan tall *Acacia* Shrublands, as an additional VFT in Australia's formal Savanna Burning GHG emissions abatement methodology. It is evident from this study that Pindan can be identified and mapped as a unique vegetation type (Fig. 3b), that it is distinguished, firstly, from other LRZ VFTs by possession of a characteristic tall (>2 m) shrub stratum dominated by *Acacia* spp, and secondly by the contribution of substantially and significantly greater shrubby fuel biomass (Table 1). Further, we demonstrate that Pindan vegetation is subject to the same regional fire regime which, until the recent advent of Savanna Burning projects, has been dominated by the frequent occurrence of extensive LDS fires (Fig. 4b).

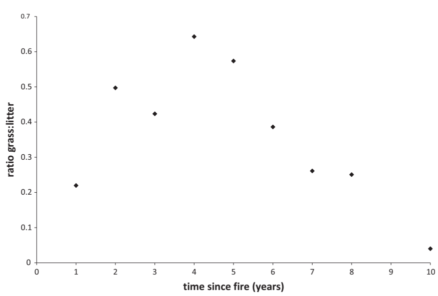

Figure 5. Ratio of grass to litter with time since fire (years).

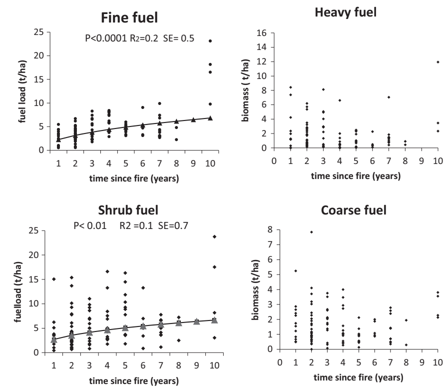

Figure 6. Fuel accumulation of respective fuel components and time since fire. Solid lines represent significant relationships between fuel load components (natural log transformed) versus time since fire (natural log transformed).

Other extensively occurring *Acacia*-dominated Savanna assemblages are likely to remain ineligible for inclusion in Australia's Savanna burning framework given that they typically support small fuel loads and are seldom burnt. Semi-closed canopy Lancewood thickets occur extensively across the Northern Territory and Queensland. These assemblages characteristically exhibit double the canopy cover of Pindan shrubland (Woinarski & Fisher 1995), with substantially lesser fine fuel loads

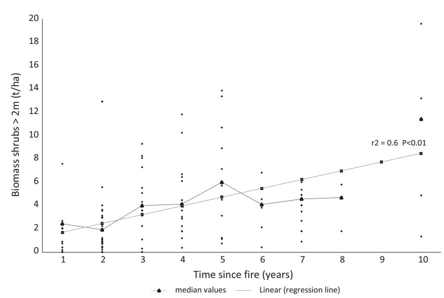

Figure 7. Live shrub biomass in >2 m shrub height class with time since fire (years).

Table 1. Summary of parameters required for deriving emission estimates from Pindan tall *Acacia* shrublands under LRZ conditions. Woodland; hummock grassland (WHu) LRZ fuel type values included for comparison (Yates *et al.* 2015)

Parameters and variables	Values (this study)		Values (Yates *et al.* 2015)		Comments	References
(a) Fuel load accumulation (n = 102)					In absence of data, we assume no seasonal differences in litter accumulation for Pindan Fine Fuels. Further work is required to determine EDS and LDS litter ratios. Alternatively apply woodland ratio	Eligible LRZ fuel types assume seasonal litter ratios as per Cuff and Brocklehurst (2015)
Fine fuels (tonnes per ha)						
TSF (years)	**Ln (ff) = 0.82 + 0.48*ln(TSF) (SE = 0.5)**		**WHu LDS**			This study
1	2.27		2.01			
2	3.17		3.40			
3	3.85		4.38			
4	4.41		5.06			
5	4.91		5.53			
6	5.36		5.86			
7	5.77					
8	6.15					
9	6.50					
10	6.84					
Non-fine fuel averages						
Shrub fuel (t/ha)	Median 4.29 (SD = 4.4)		1.84		Highly variable	This study
Coarse fuel (t/ha)	Median 1.28 (SD = 1.2)		1.85		Highly variable	This study
Heavy fuel (t/ha)	Median 1.17 (SD = 2.6)		1.15		Highly variable	This study
(b) Fire patchiness						
Proportion of area burnt (%)	EDS 76.9 (n = 78, SD = 25.5)		EDS 79			This study
	LDS 89.2 (n = 170, SD = 20.3)		LDS 97			This study
(c) Burning efficiency factor (%)					Assumes 3.79% ash component comprising residue from all fuel types	Refer Yates *et al.* (2015)
	EDS	**LDS**	**EDS**	**LDS**		
Fine fuel	77.7	82.5	79.9	83.3		This study
Coarse fuel	22.6	32.8	10.9	20.2		This study
Heavy fuel	11.7	10.7	9.8	11		This study
Shrub fuel	7.6	11.0	6.7	11.9		This study
(d) Emission factors					Detailed studies already undertaken for low rainfall Savannas	Meyer and Cook (2015)
Methane (CH_4)			**WHu WMi**[†]		Factors are as per LRZ woodland fuel types	M. Meyer (pers. comm., 2017)
Fine fuels	0.0015		0.0015			
Coarse fuels	0.0015		0.0015			
Heavy fuels	0.0158		0.0158			
Shrub fuels	0.0015		0.0015			
Nitrous oxide (N_2O)						

Table 1. (Continued)

Parameters and variables	Values (this study)	Values (Yates *et al.* 2015)	Comments	References
Fine fuels	0.006	0.006		
Coarse fuels	0.006	0.006		
Heavy fuels	0.0146	0.0146		
Shrub fuels	0.006	0.006		

†WMi = Woodland with mixed grass, LRZ fuel type. EDS, early dry season; LDS, late dry season; LRZ, low rainfall zone; TSF, time-since-last-fire.

Table 2. Emission estimates for five Low Rainfall Zone fuel types (Yates *et al.* 2015), and Pindan tall *Acacia* shrublands

Fuel type	EDS (t CO_2 e/km^2)	LDS (t CO_2 e/km^2)
Woodland with Tussock grass	16.64	24.81
Woodland with mixed grass	8.66	14.97
Woodland with Hummock grass	9.99	15.61
Open Woodland mixed grass	7.05	10.47
Shrubland – Heath with hummock grass	6.07	8.76
Pindan Acacia Shrubland (LDS litter adjusted) †	11.12	24.43
Pindan Acacia Shrubland (LDS litter not adjusted)	11.12	13.76

†Cuff and Brocklehurst (2015) woodland LDS leaf litter accumulation ratio applied. EDS, early dry season; LDS, late dry season.

dominated by leaf litter (1 t/ha: Russell-Smith *et al.* 2010), and resultant lesser fire incidence. As an obligate seeder, Lancewood needs a maturation period of at least 10 years (Russell-Smith *et al.* 2010). *Acacia* shrublands in Queensland include scrubs dominated by Mulga (*Acacia aneura*), Brigalow (*A. harpophylla*) and Gidgee (*A. cambagei*) (ALA 2017). These shrublands also experience few fires and have undergone significant decline due to clearing for pastoral activities (Myers *et al.* 2004; Australian Government 2007).

Postfire regeneration in most tropical *Acacia* taxa occurs mostly from seedling germination and less commonly through re-sprouting (Gardener & Marrinan 1992; Congdon *et al.* 2011; Radford & Fairman 2015). Most Pindan *Acacia* species are reported to reach maturation between 4 and 6 years (Gardener & Marrinan 1992). When low severity fire occurs in Pindan, mature *Acacia* individuals persist in the upper canopy, but regeneration is promoted given that germination is favoured by low intensity fires (Congdon *et al.* 2011). For Pindan (strictly *Wongai wattle*) impacted by stand replacing fires, postfire recovery to maturation has been observed to require 3–5 years (Radford & Fairman 2015), and up to 7 years (Kenneally *et al.* 1996). Although *Wongai wattle* may live for up to 20 years (Gardener & Marrinan 1992), long-lived stands are difficult to locate given the extent and frequency of regional fires.

Field sampling was challenging, especially with respect to (i) finding locations with relatively long unburnt fuels >1–2 years old given very extensive regional fires between 2013 and 2015, and (ii) implementing prescribed severe fire treatments under generally low fuel loads exacerbated by generally lower than average rainfall conditions. Despite this, it is notable that fires of moderate severity (i.e. resulting in sub-canopy leaf scorch >2 m height) comprised the majority both of observed EDS (56%) and LDS (55%) fires, and comprised 62% of EDS fires in imposed fire treatments. The relatively high proportion of moderate severity fires observed in these EDS treatments differs markedly from the lower proportion (25%) of moderate severity EDS fires from 5 years of observations from 269 LRZ plots reported in Yates *et al.* (2015). While prescribed EDS fires ignited under favourable conditions can be of low severity in shrubby semi-arid hummock grasslands (Williams *et al.* 2015), other observations suggest that EDS and LDS fires can be equally severe once continuous shrubby fuel layers are ignited under normal seasonal, and especially wildfire, conditions (Keith *et al.* 2002; Felderhof & Gillieson 2006; Williams *et al.* 2015). Collectively, these observations suggest that further studies are warranted to assess whether the seasonal distribution of fire severity may differ essentially between LRZ VFTs with extensive shrubby components (i.e. Pindan shrublands, Shrublands with mixed grasses), and those without substantial components of relatively dense, continuous shrubby fuels.

Regional benefits

Over the fire regime assessment period, 2000–2017, Pindan vegetation has been burnt on average more frequently (37%/year) than LRZ vegetation both in Western Australia (32%/year), and the north Australian Savannas region generally (25%/year). Fire regimes in all three regions have been dominated by LDS fires, but especially in Pindan shrubland vegetation (27%/year). It follows that a strategically applied EDS fire management programme focused on reducing LDS wildfires in Pindan shrublands would afford significant GHG emissions abatement benefits as per other eligible VFTs.

Applying the parameter values developed here to the emissions calculation framework outlined in the 2015 LRZ Savanna burning abatement methodology (Australian Government 2015), the average annual GHG emissions/km^2 from burnt Pindan is 12.3 t CO_2-e in the EDS; comparable with other LRZ woodland fuel types (Table 2). In the absence of accounting for LDS litter accumulation, LDS emissions increase by just 2.94 t CO_2-e; or, after adjusting for LDS litter accumulation (following Yates *et al.* 2015), calculated LDS emissions amount to 26.9 t CO_2-e, equivalent to the largest LDS emissions from LRZ woodland fuel types (Table 2). Using either of these GHG emissions estimates and allowing for 30% abatement as per experience with other projects (Russell-Smith *et al.* 2013), potential achievable annual GHG emissions abatement from Pindan shrubland vegetation would range from 37 189 to 58 733 t. CO_2-e.

Acceptance of Pindan shrubland as an eligible VFT in Australia's LRZ Savanna burning methodology would provide significant ecologic and socio-economic benefits to better manage and abate GHG emissions from regional Savanna fires. Current regional fire regimes, dominated by relatively severe LDS fire regimes at average return periods of ~3 years, are likely to be incurring significant impacts on fire-vulnerable obligate seeder shrub taxa, including *Wongai wattle* (Radford & Fairman 2015), and embedded rare habitats such as monsoon vine thickets (McKenzie & Belbin 1991). As demonstrated in other fire-prone Savanna contexts, such regional fire management programmes can also generate significant social, cultural and economic benefits for local Indigenous ranger groups, land owners and pastoral managers (Russell-Smith *et al.* 2013, 2015b; Walton *et al.* 2014).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Methods.

Appendix S2. Pindan Acacia shrubland description.