 Managing fire regimes in north Australian savannas: applying Aboriginal approaches to contemporary global problems

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 Savannas constitute the most fire-prone biome on Earth and annual emissions from savanna-burning activities are a globally important source of greenhouse-gas (GHG) emissions. Here, we describe the application of a commercial fire-management program being implemented over 28 000 km² of savanna on Aboriginal lands in northern Australia. The project combines the reinstatement of Aboriginal traditional approaches to savanna fire management – in particular a strategic, early dry-season burning program – with a recently developed emissions accounting methodology for savanna burning. Over the first 7 years of implementation, the project has reduced emissions of accountable GHGs (methane, nitrous oxide) by 37.7%, relative to the pre-project 10-year emissions baseline. In addition, the project is delivering social, biodiversity, and long-term biomass sequestration benefits. This methodological approach may have considerable potential for application in other fire-prone savanna settings.

 In a nutshell:

 • Savannas constitute the most fire-prone biome on Earth
 • Although officially banned by government regulations in many countries, use of fire plays important roles in a range of savanna livelihood and biodiversity management applications
 • This paper discusses the application of a novel fire-management project being undertaken by Aboriginal people in northern Australia that reduces greenhouse gas emissions from savanna fires

 Contemporary burning in Australia’s northern savannas

 An average of ~20% of Australia’s 1.9 million km² northern savannas region is burned each year, mostly in the latter part of the 7–8-month dry season (April–November), under progressively severe fire-weather conditions (Figure 1). Such fire activity occurs mostly in infertile areas, is unevenly distributed across the landscape predominantly under extensive, economically marginal pastoral (beef

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cattle) management systems, typically in rugged, biodiverse northern regions that experience high levels of rainfall (> 600 mm yr⁻¹). Conversely, very limited burning is typically undertaken in more fertile, productive settings, despite the potential for applying relatively intense fires to combat encroachment by woody vegetation in some pastoral regions (Williams et al. 2002).

Much of the frequently fire-affected land is under Aboriginal ownership – either under freehold title or, increasingly, under non-exclusive title arrangements (known as “native title”), as part of recent formal Australian State and Territory Government recognition of prior Aboriginal custodianship. Outside of urban settlements, Aboriginal people constitute the majority of the rural population in remote north Australian territories and, despite being “land rich”, they remain severely economically and socially disadvantaged (Russell-Smith et al. 2009b; Whitehead et al. 2009).

Fires are deliberately ignited for a variety of traditional Aboriginal and other land-management purposes; lightning ignitions are confined to the onset of the stormy monsoonal season, typically between October and December (Russell-Smith et al. 2007). Minimal infrastructure combined with a very sparsely settled rural population (< 0.1 person per km²) has resulted in a limited capacity to manage escaped fires; fire regimes in many regional settings are therefore characterized by the frequent (annual–biennial) recurrence of large (> 1000 km²), late dry-season wildfires. Despite the appearance that relatively unmodified north Australian, eucalypt-dominated savanna systems are structurally intact and healthy, contemporary fire regimes are increasingly recognized as having drastic regional impacts on sustainable land use (Russell-Smith et al. 2003b), biodiversity (Woinarski et al. 2011; Russell-Smith et al. 2012), and GHG emissions and C storage (Murphy et al. 2010; Williams et al. 2012).

The development of these contemporary burning patterns follows a breakdown in traditional Aboriginal methods of fire management, associated with societal collapse dating from the late 19th century (Ritchie 2009; Cook et al. 2012). Traditionally, burning was undertaken throughout the year over much of northern Australia, with a focus on implementing extensive “cleaning of country” management through intensive application of small patchy burns in the early–mid dry season (Russell-Smith et al. 2003b). In Aboriginal-owned West Arnhem Land, for
example, the peak traditional burning season, known as wurrungg (literally, the season for concerted fire management), coincides with the coolest part of the dry season in the middle of the year (Garde et al. 2009). Finding the economic means to reinstate this type of prescribed strategic management, and the associated social and cultural opportunities for Aboriginal custodians, is at the heart of the West Arnhem Land fire management program described below, as well as more general savanna-burning projects elsewhere across fire-prone northern Australia (Whitehead et al. 2009; Heckbert et al. 2012).

**GHG emissions accounting methodology**

Under the provisions of the Kyoto Protocol, participating Tier 1 (developed economy) countries are required to account for emissions of GHGs (specifically the long-lived chemical species methane [CH4] and nitrous oxide [N2O]) due to “prescribed burning of savannas” (UNFCCC 1998). Australia, which is the only participating Tier 1 country with substantial areas of savanna, currently contributes around 7% of accountable global GHG emissions from the burning of biomass (van der Werf et al. 2010). Typically, accountable GHG emissions contribute between 2–4% of Australia’s annual National Greenhouse Gas Inventory (NGGI; ANGA 2011a). In accordance with international accounting rules, Australia’s NGGI does not account for carbon dioxide (CO2) emissions from savanna burning, on the assumption that such fires produce no net CO2 flux (IPCC 1997). However, it is recognized that C fluxes in flammable savanna systems are dependent on fire regime characteristics, especially under changing fire frequency and intensity conditions (Beringer et al. 2007; Cook and Meyer 2009).

In accordance with other provisions of the Kyoto Protocol, which established a framework for developing market-based instruments to address anthropogenic sources and sinks of GHG emissions, a major research focus over the past decade in fire-prone northern Australia has been the development of rigorous accounting methodologies that address GHG emissions from savanna burning and the associated development of market-based projects. Australia implemented an emissions trading scheme (albeit with a fixed price during the first 3 years) beginning on July 1st 2012, so we begin by outlining the current state of development of Australia’s savanna burning methodology.

An essential premise underlying this methodology is that reductions in fire frequency result in reduced GHG emissions because more of the fuel biomass (mostly grass and leaf litter) is decomposed biologically, following pathways that produce lower relevant emissions per unit biomass consumed as compared with savanna fires. In unburned, infertile north Australian savannas, emissions of CH4 and N2O arising from biological decomposition pathways are likely to be less than 10% of that from fire (Cook and Meyer 2009).

Australia’s NGGI accounts for GHG emissions from savanna burning using a spatially disaggregated methodology that incorporates country-specific parameters and emission factors (ANGA 2011b), as allowed under IPCC rules. In its most basic form, for any region, emissions from burning savanna (E) are calculated as the product of the mass of fuel pyrolized (FP) and the emission factor (EF) of respective accountable GHG (g) species:

\[ E = FP \times EF(g) \]  
(Equation 1)

where FP is the product of the area exposed to fire (A) taking into account spatial patchiness, the fuel load (FL) in respective fuel classes, and the burning efficiency (BEF), defined as the mass of fuel exposed to fire that is pyrolized. EF(g) is defined relative to the fuel elemental content where, for C species, EF(g) is expressed relative to fuel C, and nitrogen (N) species are expressed relative to fuel N. Fuel C mass is determined from fuel mass by the fuel C content, while fuel N is derived from the fuel mass by the product of C content and the fuel N:C ratio.

Building on over a decade of research focused mostly on the West Arnhem Land region, substantial improvements have been made to this basic framework for calculating emissions from the burning of savanna (Edwards and Russell-Smith 2009; Russell-Smith et al. 2009a; Meyer and Cook 2011; Meyer et al. 2012), notably incorporating:

- Refinements to fuel load accumulation estimates, through: (1) increased stratification of fuel load classes (fine grass and litter < 6 mm diameter; coarse 6 mm–5 cm diameter; heavy > 5 cm diameter; shrubs); (2) different vegetation-fuel types (eucalypt–open-forest, eucalypt–woodland, sandstone–woodland, sandstone–heath); and (3) incorporation of extensive field-based sampling with respect to available multidecadal fire-mapping surfaces derived principally from Landsat imagery;
- Ongoing refinements to patchiness and BEF parameters, stratified by burning season (early in the year versus late dry-season conditions);
- Differentiation between EFs for grassy fuels versus those comprising substantial litter and woody fractions, based on comprehensive field assessments of the seasonality of EFs; and
- Detailed assessment of uncertainties associated with emission estimates and parameters.

These various enhancements have been incorporated into the current version of Australia’s NGGI accounting framework.

The critical EF seasonality assessment was prompted initially by mention in the Inter-Governmental Panel on Climate Change Good Practice Guidelines (IPCC 2000) that the EF for CH4 from savanna fires decreases with the progression of the dry season – this was apparently based
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on initial work done in Africa by Hoffa et al. (1999), although the results contradict earlier Australian observations (Hurst et al. 1994). If correct, a decreasing EF for CH₄ with the progression of the dry season would mean that prescribed burning as part of early season management and with the intent of reducing the extent of intense late-season fires would increase CH₄ emissions per unit biomass pyrolized. Extensive studies conducted under typical north Australian savanna grass and litter fuel conditions have observed no seasonal differentiation in CH₄ or N₂O EFs (Meyer and Cook 2011; Meyer et al. 2012).

Project accounting

Savanna burning is included in Australia’s national agricultural C offsets program, the Carbon Farming Initiative (CFI). Accredited offsets generated under the CFI are formally recognized by the Australian Government and are traded in voluntary and existing international regulatory markets, as well as in the national regulatory scheme. Australia’s formally approved methodology for accounting of GHG emissions from savanna burning (DCCEE 2012), derived mainly from research experience in West Arnhem Land, establishes strict accounting protocols prescribing all methodological and computational (including geographic information system [GIS]) procedures, vegetation-fuel type and fire-mapping (including validation) requirements, and the use of requisite parameter values, satellite imagery, and acceptable data (including website) sources. Project accounting is undertaken with respect to four implementation phases (Figure 2a):

1. Fuel estimation period: a preliminary 5-year period required to calculate available fuels (tonnes ha⁻¹) for the start of the baseline period.
2. Baseline period: a 10-year, pre-project emissions baseline is required to establish savanna-burning emissions (metric tons of CO₂ equivalent, tCO₂eq) under business-as-usual conditions, and to effectively cover contemporary interannual rainfall variability and associated fire cycles. Analysis of West Arnhem Land project data, for example, illustrates that prior to concerted management intervention from 2005, boom (fuel accumulation) and then bust (large fire) cycles occurred at around 3-year intervals (Russell-Smith et al. 2009a).
3. Transition period (optional): where government has funded the development of operational and infrastructural fire-management capacity (eg for Aboriginal communities and ranger programs), the CFI savanna-burning methodology recognizes a transitional period of up to 6 years between the pre-project baseline and formal commencement of the project. Resultant emissions are not accounted for during the transition period.
4. Project period: following acceptance of a formal project proposal, the CFI Regulator will declare agreed projects for a 7-year period, subject to meeting all other requirements. On submission of audited reports showing how the methodology was applied and justifying abatement claimed over a period of at least 1 year, the Australian Government will issue a C credit in arrears for each tCO₂eq shown to have been abated as compared with the project emissions baseline.

Figure 2. Application of Australia’s savanna burning emissions accounting methodology to the West Arnhem Land Fire Abatement Project (WALFA) area: (a) conceptual emissions accounting framework as outlined in the text; (b) seasonality of burning in the WALFA area, 1990–2011, derived principally from Landsat imagery; (c) resultant calculated savanna burning emissions in pre-project baseline period (1995–2004) and project period (2005–2011), where black lines represent mean emissions for respective periods.
Managing fire regimes in north Australia

Following years of capacity building and emissions research, the West Arnhem Land Fire Abatement Project (WALFA) became fully operational in 2005 (see Panel 1) as a voluntary emissions offset program under a 17-year arrangement with a multinational energy corporation, and formal endorsement of the project-specific accounting methodology was received from the Australian Government. WALFA operates entirely on Aboriginal lands, over a vast, remote, rugged, biodiversity-rich, and largely unpopulated landscape where, between 1990–2004, an average of over a third of the region was burned each year, predominantly by wildfires that occur toward the end of the dry season (Figures 2 and 3).

Project partners have shown that reinstatement of strategic fire management that incorporates both Aboriginal traditional and contemporary practices (eg aerial prescribed burning) and tools (eg GIS for project planning, implementation, and monitoring purposes) can substantially reduce GHG emissions associated with wildfires, while at the same time creating culturally appropriate employment opportunities for regional Aboriginal communities. An allied research program has been initiated to assess the effectiveness of improved fire management in helping to address chronic fire regime impacts on regional biodiversity.

By applying the approved CFI methodology (DCCEE 2012) to the WALFA project area, WALFA fire managers have delivered a mean annual emissions reduction (ie abatement) of 37.7% relative to the baseline period over the subsequent 7 years (from 310 024 tCO₂eq to 193 056 tCO₂eq) – including the first 2-year “transitional period” after which the project became fully operational (Figure 2d). This has been achieved through the imposition of a distinctly different fire regime during the project period, an average of 20.9% of the WALFA project area was burned in the early-season period, and 10.9% by late-season fires – whereas, in the baseline period, an average of 7.6% was burned early and 32% late (Figure 2b). Statistical comparison between mean values (one-tailed t-tests) during the baseline and project periods indicates that the project delivered significant reductions in accountable emissions ($P = 0.02$) through changes in the proportions burned early ($P = 0.003$) and late ($P = 0.003$). The mean 7.9% reduction in total area burned has not, as yet, proven significantly different ($P = 0.11$). Further contrasts in the annual pattern of fires between pre-project (1998–2004) and project (2005–2011) periods are illustrated in Figure 3.

The WALFA data also show that, in savanna systems, prescribed early-season fire management can reduce the overall extent of area burnt; that is, “leverage > 1” (Price et al. 2012). Taken together with the inherent higher degree of patchiness and the reduced severity of early-season fires, such efforts can result in both annual GHG emissions abatement and substantial additional long-term C storage in living biomass (“biosequestration”: Murphy et al. 2010). By contrast, and despite evidence that prescribed fuel-reduction treatments in forested systems can reduce GHG emissions through reduced fire severity (eg Narayan et al. 2007; Hurteau et al. 2008), other recent studies conducted in both southeastern Australian and US west coast forested ecosystems suggest that long-term mean C stand storage may in fact be reduced under such treatments (Mitchell et al. 2009; Bradstock et al. 2012).

![Figure 3. Contrast in the spatial patterning of early season (green) and late season (red) fire extent in the WALFA region for: (a) final 7 years of the pre-project baseline (1998–2004), characterized by little early season fire management and resultant extensive late season wildfires; (b) first 7 years of the project (2005–2011), characterized by development of an extensive mosaic of small, patchy, management-imposed early season fires, especially after the transitional period of 2005–2006.](image-url)
Panel 1. Rekindling fire management in West Arnhem Land

Archaeological evidence indicates that humans have managed the landscapes of the western part of the Arnhem Plateau for at least 50 000 years (Roberts et al. 1993). During that period, Aboriginal people experienced dramatic changes in climate and their environment – 18 000 years ago it was possible to walk from the plateau to what is today New Guinea across plains now submerged below the Arafura Sea (Mulvaney and Kamminga 1999).

In some parts of Arnhem Land this remarkable continuity of indigenous stewardship persisted, little changed, well after European colonization in the mid-19th century – indeed, a few families who declined to be drawn into church missions and government settlements remained on their estates and continued to implement the key elements of their ancient land-management traditions until the present day. For the most part, however, these indigenous land-management practices fell into decline. Most important of these practices was landscape-scale fire management in concert with the annual monsoonal cycle of rainfall and drying (Yibarbuk et al. 2001; Cooke 2009).

Each year, as the country dried out, Aboriginal landowners began to move through their estates, lighting many small fires – their purpose was to make the countryside easier to move through, to keep forests “open” and not choked with shrubs, to flush out game, to encourage the growth of new grass that would attract and fatten game animals, and to fulfill cultural obligations (Garde et al. 2009). As the dry season advanced, the patterning of these fires created mosaics of burned and unburned land. Back-burning from watercourses and other natural barriers created firebreaks that effectively controlled late dry-season wildfires and protected vulnerable resources, such as discrete grassland areas reserved for fire-driven kangaroo hunting later in the dry season. The effectiveness of this fine-scale fire patterning depended on many groups systematically applying what has aptly been called “fire-stick farming” (Jones 1969).

The depopulation of Arnhem Land’s indigenous people – associated mostly with disease and population drift into mission settlements – and the antipathy of white settlers and governments toward traditional Aboriginal burning practices (Ritchie 2009) resulted in replacement of environmentally sustainable regimes comprising landscape mosaics with regimes characterized by intense homogeneous late-season wildfires covering tens of thousands of square kilometers (Figures 2 and 3). Such fire regimes exhibit little internal spatial patchiness and result in deleterious impacts on fire-vulnerable flora, habitats, and sedentary fauna (Woinarski et al. 2005; Yates et al. 2008; Russell-Smith et al. 2012).

In the late 20th century, senior indigenous landowners, some of whom had grown up on their ancestral lands with little outside influence, began a dialogue with scientists about the requirements for culturally and ecologically sustainable fire management that eventually saw the reinstatement of ancient fire-management practices, updated with 20th century technologies (Figures 4–6; Cooke 2009; Whitehead et al. 2009). This cultural exchange was mediated by an emerging younger generation, committed to developing culturally appropriate land-management practices and employment opportunities on their traditional homelands. Satellite-derived fire mapping showed the extent of contemporary late dry-season wildfire and, conversely, the relative absence of traditional early dry-season burning. The implications were readily understood by all involved – elders stressed the need to “burn early”, and by so doing controlled late-season wildfires.

With modest funding from government sources and much enthusiasm from indigenous landowners, new ways of imposing strategically patterned burning on the landscape began to be tested. Helicopters were used by indigenous ranger groups to drop incendiary capsules, and back-burning was undertaken from vehicle tracks where possible. In the absence of a large, mobile, indigenous resident population, it was quickly evident that modern methods could be used to emulate ancient techniques.

Science has demonstrated that a return to “managed fire” not only benefits savanna biodiversity but, according to a concerted research program undertaken since 2000, also reduces GHG emissions on an industrial scale. This realization, and adoption of nationally accredited emissions accounting methods (DCCEE 2012), has underpinned the development of the world’s first savanna burning GHG emissions offset program, the 28 000 km² West Arnhem Land Fire Abatement Project (WALFA). Since 2005, WALFA has operated successfully as a voluntary environmental services project, offsetting over 100 000 tCO₂eq yr⁻¹ under a 17-year contract to a multinational energy corporation.

With the addition of a mix of conservation funding from government and non-governmental organizations, indigenous people are now setting benchmark standards for landscape-scale fire management and, in the process, reforging ancient links between a people and their physical and cultural heritage.
Future directions

Australia’s CFI savanna-burning methodology represents an important advance from previous iterations because it explicitly takes seasonality into account. Given that the approved methodology applies only to fire-prone north Australian savanna systems in high rainfall (>1000 mm yr$^{-1}$) zones, future work should focus on (1) extending the methodology to lower rainfall systems, where annual–biennial fire recurrence is possible (~600 mm yr$^{-1}$), and (2) the development of a complementary biosequestration methodology that addresses the longer term effects of altered fire regimes on C biomass stocks. It is well recognized that, sustained over decadal timeframes, enhanced fire management of fire-prone Australian savanna systems leads to a substantial increase in C stocks in living biomass components and associated detritus (eg Liedloff and Cook 2007; Cook et al 2010; Murphy et al 2010; Williams et al 2012), but has not yet been demonstrated in soils (Russell-Smith et al 2003a; Beyer et al 2011; Richards et al 2011).

Our conservative estimate suggests that accountable emissions reductions and C sequestration based on the methodologies described above could collectively result in annual offsets of about 5–10 MtCO$_2$eq across northern Australia, mostly from Aboriginal lands. Carbon emission offsets achieved through savanna burning projects have the potential to transform both Aboriginal rural economies, through the establishment of culturally appropriate enterprises (Whitehead et al 2009; Heckbert et al 2012), and broader land-management sustainability, through the generation of conservation stewardship options on marginal pastoral lands (Douglass et al 2011). However, a considerable challenge to the realization of such opportunities lies in the development of robust institutional and governance frameworks that cater principally to the traditional cultural requirements of rural Aboriginal communities, including communal land–title arrangements (Whitehead et al 2008).

Subject to the development of appropriate parameters and EFs, the CFI savanna-burning methodology developed for northern Australia could be applied to rural and savanna management situations in other fire-prone continental settings, including, for example, savanna landscapes extensively and frequently burned by late-season wildfires in parts of Africa (eg Angola, Mozambique, Namibia, Zambia; Archibald et al 2009; Beatty 2011) and formerly traditionally managed savannas in South America (eg Mistry et al 2005; Bilbao et al 2009).

However, the practicality of such applications first needs to be assessed in light of major challenges: (1) the human, ecological, and meteorological drivers of fire emissions and the potential to appropriately modify fire regimes to reduce those emissions (see Archibald et al 2010; Archibald 2011); (2) the complex tenure, governance, and regulatory environments that typically affect indigenous peoples and rural communities in many “provision of environmental services” projects (Muradian et al 2010; Lyster 2011) – indeed, demonstrating security of tenure may be particularly problematic in the case of biosequestration projects that need to address “permanency” at multi-decadal scales (Fahey et al 2010). A further caveat is that savanna-burning emissions reduction and biosequestration projects may be inappropriate in pastoral rangeland situations where relatively severe fire regimes may need to be prescribed to address encroachment of woody vegetation (Scholes and Archer 1997; Dyer et al 2001; Wigley et al 2010; Archibald 2011).

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References


Australia: rekindling the wurrk tradition. Melbourne, Australia: CSIRO.
Meyer CP and Cook GD. 2011. Seasonality in greenhouse gas emission factors from savanna fires. Melbourne, Australia: CSIRO.