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

Jeremy Russell-Smith[1,2*], Garry D Cook[3], Peter M Cooke[4], Andrew C Edwards[1], Mitchell Lendrum[5], CP (Mick) Meyer[6], and Peter J Whitehead[2]

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 km^2 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.

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Savannas – defined broadly as tropical and subtropical grasslands (characterized by grasses with C_4 photosynthetic pathway) with varying densities of tree cover – constitute the most fire-prone ecosystems on Earth. They occupy one-sixth of the planet's land surface and support a tenth of the human population, and while rates of land-use change are uncertain, these systems are likely to experience twice the rate of conversion as compared to tropical forests (White *et al.* 2000; Grace *et al.* 2006). Almost 60% of savannas, and two-thirds of the human populations that live in these areas, are located in sub-Saharan Africa, with other major occurrences (in order of geographic extent) in Australia, South America, and Asia (White *et al.* 2000; Lehmann *et al.* 2011). The deliberate burning of savannas, for a variety of agricultural, pastoral, and traditional management purposes, contributes as much as 10% of annual total global carbon (C) emissions and 44% of estimated C emissions from all sources of biomass burning (IPCC 2007; van der Werf *et al.* 2010).

In a nutshell:

- Savannas constitute the most fire-prone biome in the world
- 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

In this paper, we describe the context of contemporary prescribed burning practices in Australia's northern savannas region. We then explore the application of a novel greenhouse-gas (GHG) emissions abatement project for burning savannas which combines traditional indigenous (Aboriginal) management practice with a recently developed GHG emissions accounting framework, designed to deliver ecologically and economically sustainable prescribed burning at landscape scales. The approach has considerable potential for application in fire-prone savanna settings around the world. Broadly similar GHG emissions reduction and C-storage schemes using prescribed fire management have been described for fire-prone forested landscapes in Europe (Narayan *et al.* 2007; Vilen and Fernandes 2011) and North America (Hurteau *et al.* 2008; Wiedinmyer and Hurteau 2010).

Contemporary burning in Australia's northern savannas

An average of ~20% of Australia's 1.9 million km^2 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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[1] *Darwin Centre for Bushfire Research, Charles Darwin University, Darwin, Australia* [*] *(jeremy.russell-smith@cdu.edu.au);* [2] *North Australian Indigenous Land and Sea Management Alliance, Darwin, Australia;* [3] *CSIRO Ecosystem Sciences, Darwin, Australia;* [4] *Warddeken Land Management, Darwin, Australia;* [5] *Dept of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Canberra, Australia;* [6] *CSIRO Marine and Atmospheric Research, Melbourne, Australia*

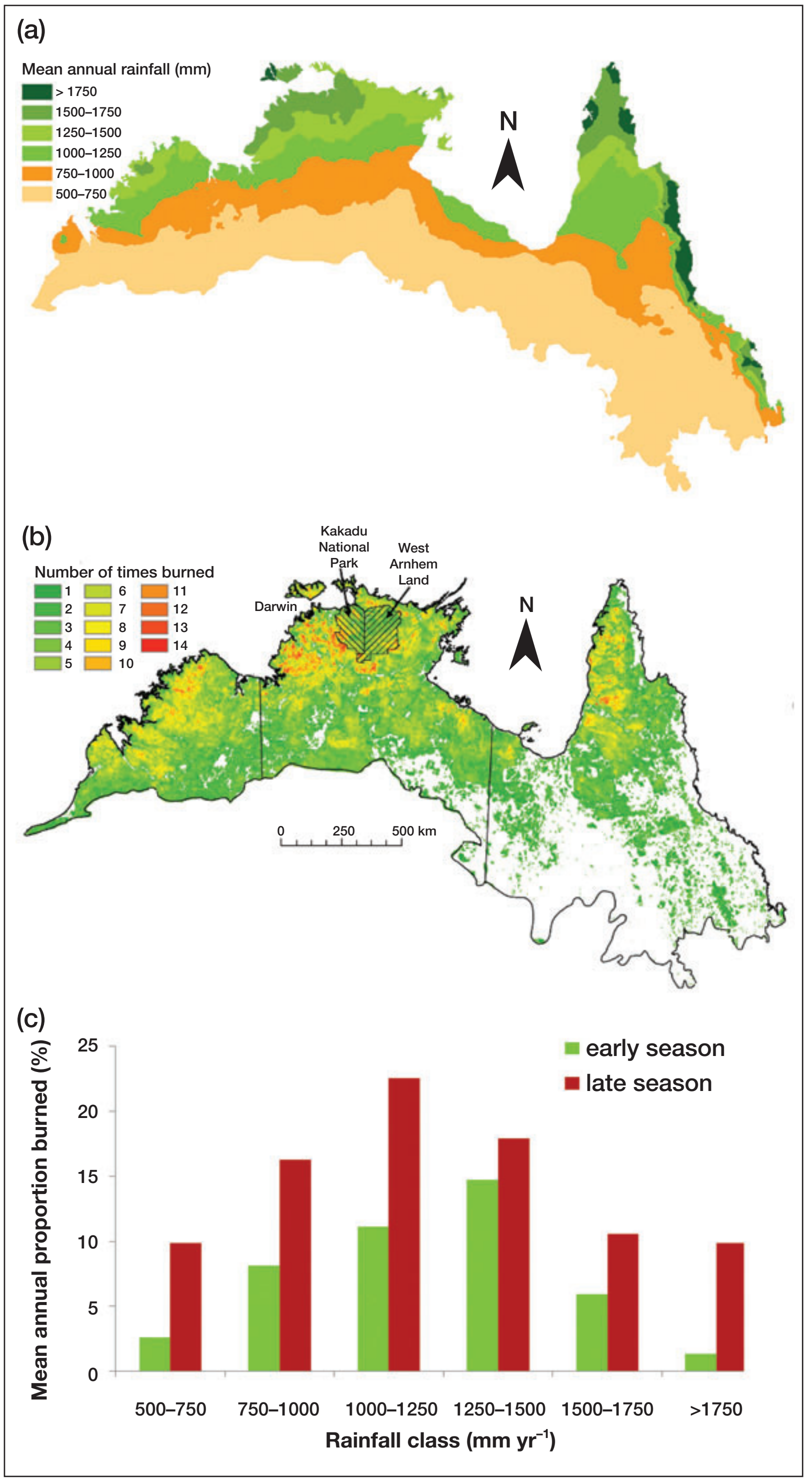

Figure 1. *Relationships between fire incidence and rainfall characteristics in Australia's northern savannas: (a) rainfall isohyets (contours) for the period 1969–2008; (b) fire frequency (number of times burned), 1997–2010, derived from advanced, very high resolution radiometer (AVHRR) imagery; and (c) mean seasonality of fire occurrence for respective rainfall classes, 1997–2010, where early season fires refer to those occurring before August. Savanna regions are defined according to Tropical Savannas Cooperative Research Centre guidelines (Fox* et al. *2001).*

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; White-head *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 km^2) 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 km^2), 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 *wurrgeng* (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 [CH_4] and nitrous oxide [N_2O]) 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 (CO_2) emissions from savanna burning, on the assumption that such fires produce no net CO_2 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 CH_4 and N_2O 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:

$$E = FP * EF(g) \qquad \text{(Equation 1)}$$

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 CH_4 from savanna fires decreases with the progression of the dry season – this was apparently based

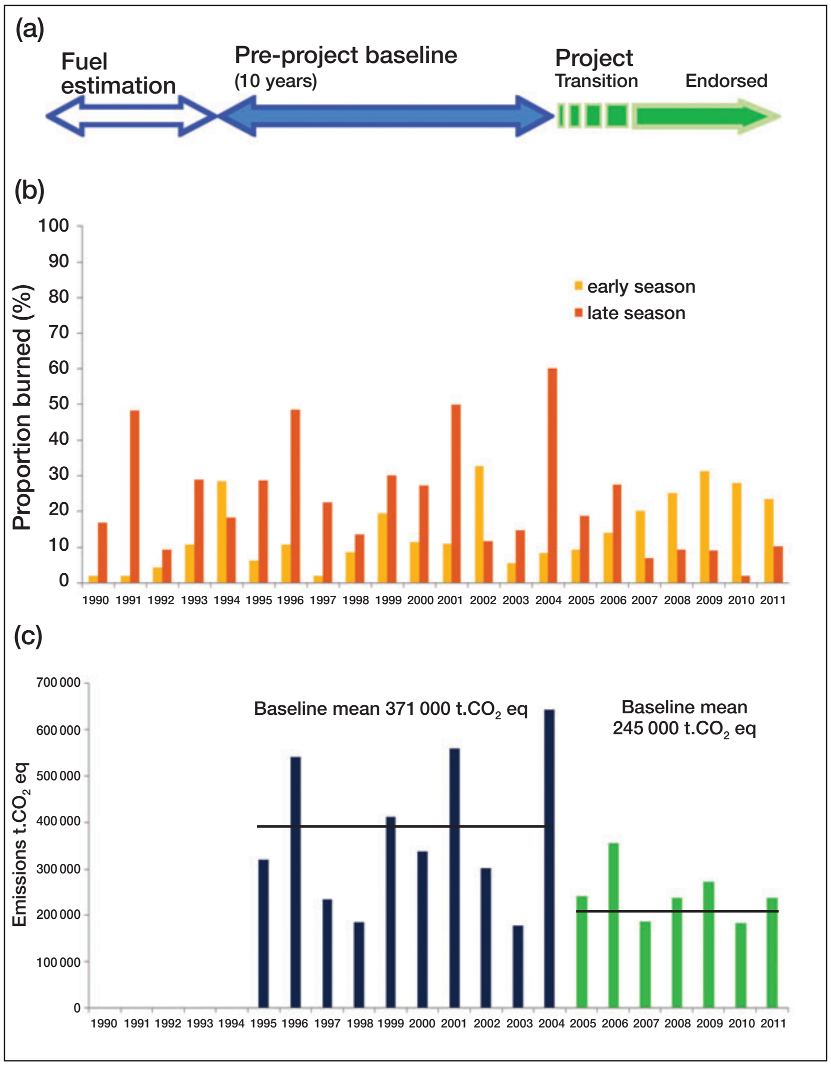

Figure 2. *Application of Australia's savanna burning emissions accounting methodology to the West Arnhem Land Fire Abatement Project (WALFA) area: (a) conceptual emissions accounting framework as outlined in the text; (b) seasonality of burning in the WALFA area, 1990–2011, derived principally from 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.*

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 CH_4 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 CH_4 emissions per unit biomass pyrolized. Extensive studies conducted under typical north Australian savanna grass and litter fuel conditions have observed no seasonal differentiation in CH_4 or N_2O 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):

- Fuel estimation period: a preliminary 5-year period required to calculate available fuels (tonnes ha^{-1}) for the start of the baseline period.
- Baseline period: a 10-year, pre-project emissions baseline is required to establish savanna-burning emissions (metric tons of CO_2 equivalent, tCO_2eq) 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).
- 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.
- 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 tCO_2eq shown to have been abated as compared with the project emissions baseline.

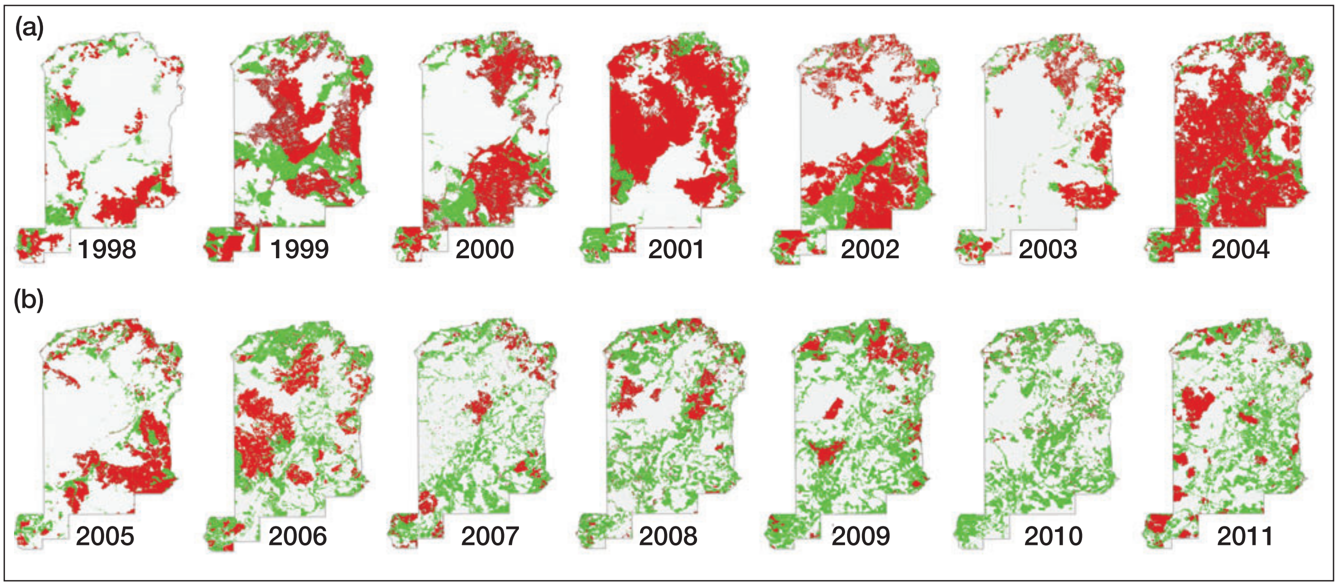

Figure 3. *Contrast in the spatial patterning of early season (green) and late season (red) fire extent in the WALFA region for: (a) final 7 years of the pre-project baseline (1998–2004), characterized by little early season fire management and resultant extensive late season wildfires; (b) first 7 years 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.*

■ West Arnhem Land Fire Abatement Project

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 tCO_2eq to 193 056 tCO_2eq) – 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).

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 wildfire 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).

Figure 4. *Senior custodians and rangers plan the upcoming year's fire-management program.*

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).

Figure 5. *A ranger securing a firebreak with a mechanical leaf blower in remote rocky terrain.*

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.

Figure 6. *Aerial prescribed burning is used to establish strategic firebreaks across the Arnhem Plateau in the early dry season under mild fire-weather conditions.*

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 km^2 West Arnhem Land Fire Abatement Project (WALFA). Since 2005, WALFA has operated successfully as a voluntary environmental services project, offsetting over 100 000 $tCO_2eq\ yr^{-1}$ 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_2eq 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 range 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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