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Above- and below-ground carbon dynamics of different fire regimes in extensive grazing systems in northern Australia

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Abstract
This paper reports initial field studies and modelling of carbon stocks under alternative fire regimes in northern rangelands. The field studies in the Victoria River District suggested that fire regime had no effect on aboveground carbon stocks (AGC) in an open grassland/shrubland. In an open Eucalypt woodland the overall effect of fire season was not significant and the effect of fire frequency was inconsistent. However, modelling suggested that regular burning to maintain low woody density and promote grass production will reduce above- and below-ground carbon stocks in the open woodland. The opportunities for pastoralists to increase carbon stocks by reducing fire frequency are limited in many regions and will depend on vegetation type and current fire regime. Any carbon gains are likely to be modest and will be associated with greater tree and shrub density, which may adversely affect pasture and livestock production.

Introduction
The potential role of Australia's rangelands as a significant carbon sink that could contribute to managing the nation's carbon balance and allow land managers to earn income through carbon credits has been the subject of considerable speculation. However, there currently is a lack of detailed data to inform questions about the changes in management that might offer carbon gains and the magnitude of those gains.

Fire is used for a variety of purposes in many of Australia's rangelands including to control invasive native and non-native woody shrubs and tree regrowth. Because fire releases carbon from biomass to the atmosphere, mediates the uptake of carbon by vegetation and alters rates of carbon transfer between terrestrial pools (Williams *et al*. 2012), fire management may influence carbon stocks in vegetation and soils. This paper reports some initial field studies and modelling of carbon stocks in relation to fire management in grazed rangelands in northern Australia.

Kidman Springs fire study
A 20-year study of the effect of fire regime on the tree-grass balance at the Northern Territory Government's Victoria River Research Station (annual rainfall approximately 650-700 mm) offers the opportunity to explore the effect of alternative fire regimes on carbon stocks in grazed pastures. The study is occurring on two pasture communities, an open eucalypt savanna woodland on red Calcarosol soil and a savanna grassland-open shrubland on grey Vertosol soil.

The experimental fire regimes are the combination of three fire frequencies (every 2, 4 or 6 years) and two fire seasons, either in the early (June) or late (October) dry season. Unburnt treatments are included. The sites are within large paddocks grazed at usual district stocking rates.

Field studies
Aboveground carbon (AGC) stocks on each plot were estimated in May 2011 by field measurements of all aboveground biomass, including live and dead vegetation, surface litter and woody debris. AGC was generally greater on the woodland site (mean = 11.0 t/ha) than the grassland/shrubland site (mean = 3.8 t/ha) due to the greater abundance of trees on the former site, which contributed the greatest proportion to total AGC (Figure 1). Overall, the effect of season of fire on AGC on this site was not significant, but fire frequency and the interaction with season were significant ($P = 0.01$ and $P = 0.023$, respectively). However, the response of AGC was inconsistent in relation to fire frequency particularly for the early fires, with AGC being lowest for the four-year fire frequency (6.7 t/ha cf. 12.7 and 11.2 t/ha for 2 and 6 year, respectively), although this was only significant ($P = 0.05$) compared to the 2-year treatment. For the late fires, AGC on the 6-year treatment was significantly ($P < 0.05$) greater than the other two regimes (17.9 vs. 6.0 and 6.3 t/ha for 2 and 4 year, respectively), although it should be noted that an error in the burning schedule meant that the late 6-year treatment had not been burnt for 10 years prior to our measurements. Since no data on initial AGC are available it is not known if inherent site differences are also confounding the results. On the grassland/shrubland site AGC was not affected by fire season, fire frequency or their interaction ($P > 0.05$ for all).

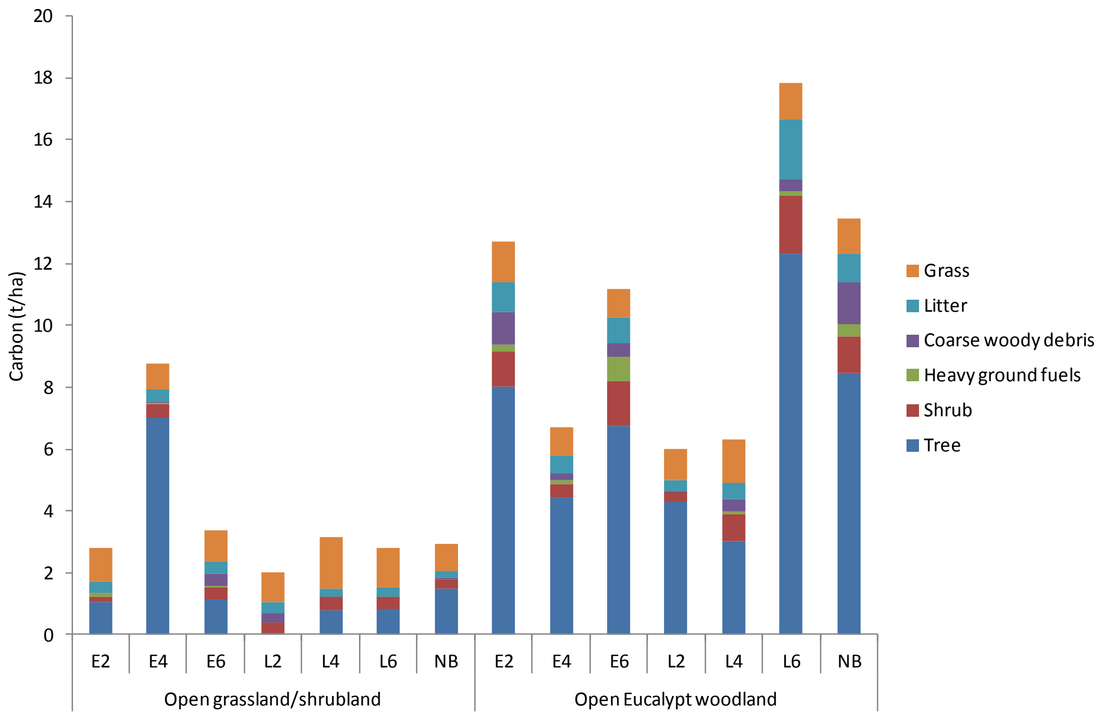

Figure 1. Carbon stocks in the various components of aboveground biomass on the Kidman Springs fire plots in two pasture communities in May 2011. E2 = early dry season fire every two years, L2 = late fire every two years etc. NB = not burnt.

Modelling
The Century model was used to simulate historical and future carbon dynamics of these fire regimes on the open woodland site. We assumed cool fires every five years prior to pastoral development (1900) to represent Aboriginal burning and a hot wildfire every 10 years after development until the experiment began (1993), with the experimental fire regimes continuing until 2050. Grazing was included following pastoral development. The results for selected fire regimes are presented in Figure 2.

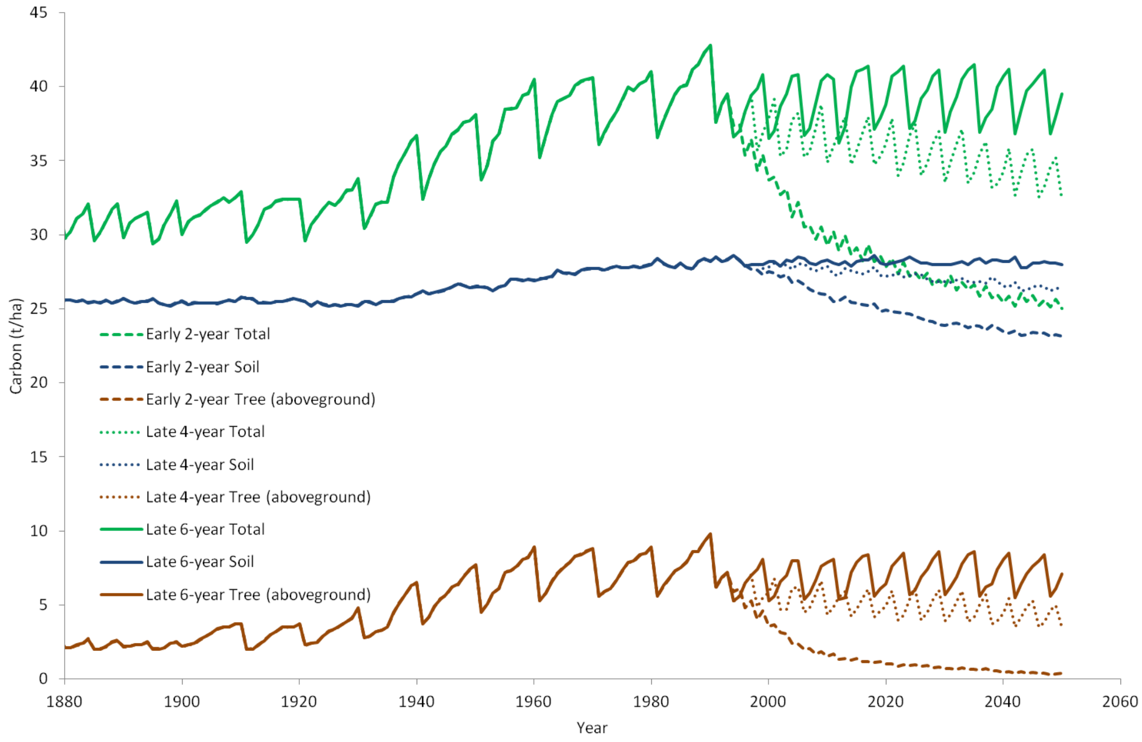

Figure 2. Modelled organic carbon trajectories for the open woodland site at Kidman Springs for the tree (aboveground) and soil (to 30 cm) components and total system carbon from before pastoral settlement in 1900 and following implementation of three of the experimental fire regimes in 1993.

These results suggest that a reduction in fire frequency following pastoral development may have increased carbon stocks due to an increase in the abundance of woody plants. Subsequently, a late fire every four years (recommended to manage woody species; Cowley *et al*. 2011) may have reduced total carbon stocks by about 3-4 t/ha to the present day, with a continuing slow decline over the next few decades under this regime. The soil carbon stock (the largest carbon pool) reflects the general trend in aboveground carbon, but the shifts are substantially more subdued. Initial modelling indicates that both early and late 2-yearly fires (late fires not shown) reduce aboveground and soil carbon stocks more rapidly than 4-yearly fires, while both early (not shown) and late 6-yearly fires have a negligible effect on carbon stocks.

Regional scale modelling

We used the Flames model (Liedloff and Cook 2007) to explore the effect of fire regime on AGC in regions across the northern rangelands. We simulated the current fire regime for key soil types in each region and for scenarios with twice or half the current fire frequency, and with no fire. The results were variable. Selected results are presented in Table 1. Altering fire frequency had a small effect on AGC in most regions. Even if fire was completely eliminated increases in AGC were limited to about 3 t/ha over 50 years.

Table 1. Modelled aboveground carbon stocks (t/ha) for selected regions under current fire regimes (ranked from lowest to highest), and after 50 years with half or twice the current fire frequency and with no fire. Data are means for all modelled soil types within each region.

	Fire frequency			
IBRA region	Current (mean and SD)	Half current	Twice current	No Fire
Northern Kimberley	17.6 (13.6)	17.3	18.2	22.0
Gulf Fall and Uplands	19.7 (2.3)	19.0	19.5	21.5
Pilbara	20.3 (6.4)	20.3	20.3	20.6
Mitchell Grass Downs	21.8 (2.1)	21.8	21.9	22.6
Einasleigh Uplands	25.3 (4.1)	25.7	25.3	28.0
Gulf Plains	27.8 (3.8)	26.9	27.1	30.3
Sturt Plateau	30.4 (1.8)	30.6	30.1	30.5
Brigalow Belt North	56.4 (3.7)	56.7	56.9	57.4

Discussion

The preliminary nature of this work, the inconclusive field results and the limited validation of model outputs should be kept in mind when considering the following points. Fires in this region tend to be fuelled by grass and litter, which are only a small proportion of the aboveground carbon and recover quickly following fire. Fire will have a more enduring and substantial influence on carbon stocks where a fire regime alters woody abundance. More frequent fire generally appears to reduce woody plant density and cause declines in above- and below-ground carbon.

The modelling results suggest that the opportunities for pastoralists to increase carbon stocks by altering fire frequency are limited in many regions of northern Australia. The effect of changing fire regime on carbon stocks in a given situation will depend on several factors including the woodiness of the vegetation and current fire regime. Regions with frequent fire offer the greatest potential carbon gains, but to increase carbon stocks a substantial reduction in fire frequency would be required. Even then the effect on carbon stocks is likely to be quite modest (although small gains over a large area may be worthwhile if they can be verified). However, these gains will be associated with greater tree and shrub density, which may adversely affect pasture and livestock production. The potential trade-off between livestock returns and income from carbon credits would need to be evaluated when planning changes in fire management.

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