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Carbon accounting, land management, science and policy uncertainty in Australian savanna landscapes: introduction and overview

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Introduction

Tropical savannas are a substantial biome globally (Huntley and Walker 1982; Tothill and Mott 1985). They occur extensively across the world's seasonal tropics, constituting ~12% of the world's land surface. Australia's tropical savannas are an extremely important natural and cultural resource nationally, occupying approximately two million square kilometers—or about a quarter of the continent. They occur north of ~20°S in northern Western Australia (WA), the northern half of the Northern Territory (NT) and inland of the Great Dividing Range in northern Queensland (Fig. 1; Mott *et al*. 1985). These vast landscapes are generally intact, structurally, with relatively little tree clearing for agriculture and forestry compared with southern Australia (Ridpath 1985; Braithwaite and Werner 1987), and account for ~30% of Australia's terrestrial carbon stocks (Barrett 2002). However, the savannas are subject to recurrent, extensive disturbance, resulting especially from grazing of domestic livestock and fire (Williams *et al*. 1997*a*, 2002).

Climate change is upon us, we need to mitigate and adapt, and greenhouse gas abatement is a central, global climate-change issue (Pittock 2005). Given the extent and relative intactness of our native savanna ecosystems, we may ask what role the savannas may play in the nation's carbon budget, in particular their potential role in greenhouse gas abatement. Australia, although not a party to the Kyoto Protocol, has ratified the United Nations Framework Convention on Climate Change (UNFCCC), and is committed to greenhouse gas abatement. Indeed, in May 2004, the Australian Government announced the *Greenhouse Action in Regional Australia Programme*, committing some AU$20 million over 4 years to build capacity in the agriculture and land-management sectors of rural and regional Australia to enhance greenhouse gas abatement (Australian Greenhouse Office 2004). This, in turn, implies potentially different land-management priorities and procedures; however, there are numerous questions and uncertainties concerning the intersection of land management and carbon accounting. What are the stocks and fluxes of carbon in savannas? Are the savannas a carbon source or sink? How does disturbance and contrasting land use affect the carbon stocks and over what timeframe? Is it possible to enhance greenhouse gas abatement by better land management in the savannas? What accounting rules might apply to evaluating land use and its impact on carbon in savannas? What tools, current and yet to be developed, scientific and policy, might we need to assess these questions? And how might we identify the benefits and costs of change?

Research into these aspects of carbon dynamics in savannas is of international significance because savannas account for a significant amount of the world's terrestrial carbon (Scholes and Hall 1996). Savannas are undoubtedly a source of greenhouse emissions (Pereira 2003) but they may also offer significant potential as a carbon sink (Scurlock and Hall 1998; Lal 2002; Chen *et al*. 2003).

The aim of this Special Issue of *Australian Journal of Botany*, then, is to address these issues and questions, with a view to highlighting where scientific and policy uncertainties lie, and indicate how such uncertainties may be reduced. The papers arise from a workshop held in Darwin in January 2003, jointly sponsored by the Cooperative Research Centre for Tropical Savanna Management (TSMCRC) and Cooperative Research Centre for Greenhouse Accounting (GACRC). This Special Issue of *Australian Journal of Botany* comprises the 11 invited papers from the workshop.

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Fig. 1. Map of Australia indicating extent of the tropical savanna region of northern Australia (dark shaded). Source: Tropical Savanna Management CRC.

Australian savannas: the biophysical context

Savannas consist of a discontinuous stratum of trees over a more or less continuous layer of grasses (Huntley and Walker 1982). Like savanna landscapes elsewhere in the world, the climate in Australian savannas is strongly seasonal with respect to rainfall. There is a hot, summer wet season, during which most of the rain falls, and a warm, dry season in the cooler months, during which little or no rain falls (Cook and Heerdegen 2001). The vegetation is overwhelmingly savanna open-forest and woodland, most dominated by eucalypts, with a grass understorey. There are dozens of different vegetation types mapped at 1 : 1 000 000 and 1 : 2 000 000 (Wilson *et al.* 1990; Fox *et al.* 2001).

Growth is prolific in the 4–5-month wet season, and most carbon is fixed during this time (Eamus and Prior 2001; Eamus *et al.* 2001). Because the dominant trees are evergreen, reproduction, transpiration and photosynthesis occur in the trees during the dry season (Williams *et al.* 1997*b*, 1999; Eamus *et al.* 1999; O'Grady *et al.* 1999). As a consequence savannas continue to fix carbon through the dry season (Eamus *et al.* 2001). However, the biome in general is prone to frequent fire, especially in the more mesic areas (Williams *et al.* 2002). Savanna fires contribute substantially to national greenhouse budgets, through the production of methane and nitrous oxide, and affect the size of this savanna carbon sink (Williams *et al.* 2004).

The composition and structure of savannas are strongly dependent on variations in available moisture and soil nutrients, with secondary determinants being disturbances owing to fire and herbivory (Skarpe 1990; Scholes and Walker 1993; Koch *et al.* 1995; Walker and Langridge 1997; Williams *et al.* 1996). 'Mesic' savannas occur where mean annual rainfall exceeds ~900 mm, whereas the 'semi-arid' savannas occur where mean annual rainfall is less than 900 mm (Williams *et al.* 1997*a*). Landforms include the flat lowland sand and loam plains, dominated by eucalypt and sometimes acacia woodlands, the rugged, rocky escarpments, slopes and plateaux of the 'stone country', where pockets of rainforest, woodland, shrubland and heaths may occur, and the extensive treeless 'black-soil plains', where the dominant soils are cracking clays. Climate change may already be affecting the climate of some savanna regions, with increasing rainfall and declining pan evaporation occurring in north-western Australia (Nicholls 2004; Roderick and Farquhar 2004).

People, land use and natural-resource management in Australian savannas

The human population of the Australian savanna region is low; 6% of the Australian population at a density of 25 persons per 100 km^2, compared with 400 persons per 100 km^2 in southern Australia (Johnson 1999). Even then, a high proportion of that population lives in regional towns and cities.

Australia's savannas are characterised by relatively low soil and pasture productivity, coupled with a high degree of spatial and temporal variability in resource condition at a range of scales. Consequently, economic options in terms of traditional agricultural and forestry activity are limited, and the predominant agricultural land use is extensive grazing for beef-cattle production, with the savannas running nearly 6 million animals, or 25% of Australia's cattle herd (McDonald *et al.* 2004). Aboriginal freehold land, used extensively for customary purposes, is the next most extensive land use and tenure type. Lands set aside for conservation management are also a significant component of the savanna region. Other economic uses of terrestrial natural resources tend to be localised (e.g. mining, tourism, horticulture) or adapted to the spatial and temporal variability of the environment (e.g. harvesting of wildlife, particularly by Indigenous people). The mining sector, although occupying relatively little land, contributes by far the greatest amount to the savanna economy (Gray 1996).

Natural-resource management, carbon and savannas, an emerging issue for the 21st century

Land use and the economic base of the savannas of Australia are both rapidly changing. The economy of the savannas is becoming more diverse, with industries such as tourism playing an increasingly important economic role.

Fire regimes have changed over 200 years of European land use (Russell-Smith *et al*. 2003*a*), areas have and will continue to be cleared, woody 'thickening' is becoming more apparent (Burrows *et al*. 2002) and there have been declines in biodiversity recourses (Franklin 1999; Woinarski *et al*. 2001). Aboriginal people own and manage a substantial proportion of the savannas (e.g. about half of the Northern Territory; Whitehead *et al*. 2003), and there is potential for a 'hybrid' economy (*sensu* Altman 2001; Altman and Cochrane 2005) that combines Indigenous ecological knowledge and customary practice with western biophysical and social science. In addition, there is an increasing expectation from the community that savannas and other natural ecosystems will be managed for environmental and cultural values, as well as economic values.

Natural-resource management in Australia's savannas in the 21st century will be carried out in this complicated, changing context, and will also have to administer and account for greenhouse emissions and carbon sequestration. Nevertheless, the relatively intact natural systems of the northern Australian savannas represent a natural asset of global significance. The tropical savannas of northern Australia are increasingly recognised as offering the greatest potential for cost-effective natural-resource management, because existing natural and cultural assets and functioning ecosystems can be maintained, and, ergo, deployed to provide ecosystem services that may only be beginning to emerge.

For example, it is axiomatic that widespread savanna fire is the major source of global biomass burning and associated greenhouse gas emissions (Hao and Liu 1994; Pereira 2003). Indeed, in the Northern Territory, biomass burning contributes to ~50% of that jurisdiction's total greenhouse gas emissions (Australian Greenhouse Office 2005). Nevertheless, current indications are that, at least in the mesic savannas of the Darwin and Katherine region, the savannas are net sequesters of carbon, despite a relatively high fire frequency (Chen *et al*. 2003) and that sequestration potential can be increased by managing for reduced fire frequency and extent over vast landscapes (Williams *et al*. 2004). This may be achieved by prescribed fuel-reduction burning. Alternatively, if grazing pressure from domestic livestock increases as a result of more common use of supplements and better animal management, then both decreased grassy fuel load and increased patchiness of fuel may reduce potential fire frequency (Dyer *et al*. 2001).

In managing for carbon outcomes (reduced emissions, enhanced sequestration in biomass and soil, and any of the associated economic flows), via reduced fire frequency there are likely to be direct collateral benefits. For example, the current regime of frequent, intense and extensive fires across the savannas, especially the mesic savannas, is contributing to the decline of a broad range of plant and animal species (e.g. Franklin 1999; Bowman *et al*. 2001; Woinarski *et al*. 2001; Russell-Smith *et al*. 2002; Woinarski and Fisher 2003), and appropriate conservation management of these resources requires reduction in fire extent and frequency.

Further, with respect to biodiversity conservation, what is required is better management of extensive landscapes and tenures, including the Aboriginal-owned lands and the pastoral estate, rather than just better management of the reserve estate. The economic basis for such improved management, however, is currently extremely limited, and further constrained by limited human capacity, poorly integrated natural-resource planning and an incomplete landscape-management toolkit.

Carbon trading, or at least the provision of greenhouse gas offsets to meet national abatement requirements, may offer some possibility of providing an alternative or additional land use and valuation of these environments, and hence a mechanism for their improved management. Furthermore, over much of the landscape the changes in land-management regimes necessary for reduced greenhouse gas emissions are similar to the changes needed to mitigate biodiversity impacts from adverse burning. Current abatement projects such as the Arnhem Land Fire Abatement (ALFA) Project in the Northern Territory have attracted both private-sector and public funding support for the development and application of better fire management in sparsely populated landscapes of high ecological significance. Outcomes of improved fire management include not only reduced greenhouse gas emissions and better biodiversity conservation, but economic and employment opportunities for Indigenous communities (Russell-Smith *et al*. 2003*a*, 2003*b*).

This Special Issue

The emerging 'carbon economy' is likely to have profound implications for land use and the economic base of northern Australia, and indeed other regions across the world where the landscape is so dominated by native ecosystems and the population and/or infrastructure base is relatively sparse. But how might it work, given current scientific, policy and economic uncertainty? How might we account for the implications of changing land use at extensive, regional and sub-continental scales? How do we best measure the components of the carbon stocks and fluxes in Australia's savannas? How might changes in land management affect carbon emissions and sequestration? What are the international, regional, local and institutional pathways, and constraints, to the development of a carbon economy? Are there regional collateral benefits for managing carbon? And how might schemes be implemented, and made to work, practically, socially and commercially?

In this Special Issue, we explore these issues, with respect to rules and tools. We focus on the intersection between carbon accounting, land use, and land-use change, and what this may mean for remote and regional northern Australia and, indeed, other similar landscapes of the world. Henry *et al*. open proceedings and review the national and international scene, especially with respect to national and international accounting schema and protocols. Then follow a series of empirical papers that address the biophysical tools available for estimating carbon stocks and fluxes at different scales in savannas. Three papers discuss above-ground biomass, using allometry. Williams *et al*. examine the applicability of general predictive allometric equations for the estimation of tree biomass. Cook *et al*. use allometric relationships between biomass and stem cross-sectional area, and algorithms relating tree survival to fire intensity, to predict the impacts of fire on carbon stocks of live trees. Fensham addresses the issue of accounting for dead standing wood, a component of savanna carbon stocks that has been hitherto little studied. The next two papers address land use and soil carbon: Harms *et al*. assess the impact of land clearing on soil carbon, whereas Krull and Bray examine the relationships between stable carbon isotopic signatures of soil organic matter and changes in the relative abundance of the two main components of savannas, C_3 trees and C_4 grasses. Studies of ecosystem productivity have been enhanced in recent years by two plant-ecophysiological techniques: eddy covariance, and free-air carbon dioxide enhancement (FACE). Hutley *et al*. evaluate the utility of eddy covariance studies, which provide key measurements of ecosystem productivity, and also provide data to calibrate and validate canopy- and regional-scale carbon-balance models. Stokes *et al*. describe the application of a savanna FACE experiment. Estimating carbon stocks and fluxes at local scales with empirical and experimental studies is challenging enough, but how might estimates be made at larger scales? Modelling and data integration, coupled with remote-sensing tools, are the key tools here. Barrett *et al*. and Hill *et al*. each present modelling approaches to estimating carbon stocks at scales that are relevant to land management and policy development within regions. Finally, there is of course a crucial socio-economic element to managing for carbon in savanna landscapes, because people, their property and their values are inextricably involved in the process. To this end, Vella *et al*. discuss institutional and socio-economic dimensions to the problem of engaging people in the business of managing for carbon in savannas, and illustrate potential pathways and constraints to carbon management, in the context of regional development.

There will remain, undoubtedly, constraints and uncertainties. However, the capacity to plan and act at extensive geographic scales is developing, and it is at least technically feasible to manipulate significant variables, particularly fire, at a landscape scale. The combination of low density of human population and very large areas of structurally intact landscapes under contiguous, uniform tenures presents many opportunities to influence landscape carbon balances and fluxes.

These opportunities are timely. Compared with the situation a decade ago, we have access to improved monitoring technologies and tools, and an increasingly sophisticated understanding of the processes driving landscape change (Russell-Smith *et al*. 2003*b*; Whitehead *et al*. 2005). Indeed, much of our recent understanding of savanna form and function has been gained since the first Australian greenhouse inventory in 1994, a consequence of undertaking carbon accounting to meet international greenhouse obligations. We have a better appreciation of human–landscape interactions, and improved approaches to working with land owners and managers to better effect (Dyer *et al*. 2001; Whitehead *et al*. 2003). Our capacity to communicate and to gather and deliver information improves daily, and we enjoy relatively high levels of co-operation across administrative jurisdictions and across industrial sectors, despite differences in values, priorities and perceptions. Information on the quantum and dynamics of carbon stocks in savannas will not only facilitate more sustainable management now, but provide a basis for knowledge concerning the impacts of, and adaptations to, climate-change scenarios.

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