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Carbon sequestration and biodiversity restoration potential of semi-arid mulga lands of Australia interpreted from long-term grazing exclosures

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ABSTRACT

Limited data regarding soil carbon (C) sequestration potential and biosequestration potential in arid and semi-arid environments is an impediment to appropriate policy formulation directed at greenhouse gas abatement. This paper assesses the terrestrial C biosequestration and biodiversity restoration potential of the semi-arid mulga lands of eastern Australia by measuring above and below ground C, and by making floristic biodiversity assessments in old grazing exclosures.

Grazing exclusion increased water infiltration rates and water retention capacity in the soil. Exclosures also had increased herbaceous cover and decreased bare ground. Biodiversity benefits included higher species richness and increased abundance of native grasses, many of which have become locally rare under increased grazing pressure.

The study indicates that in the absence of grazing, soil and above ground biomass, when combined, has potential carbon sequestration rates of between 0.92 and 1.1 t CO_2-e ha^{-1} year^{-1} over a period of approximately 40 years. The contribution to these figures from soil C sequestration is approximately 0.18 t CO_2-e ha^{-1} year^{-1}, with above ground biomass contributing an additional 0.73–0.91 t CO_2-e ha^{-1} year^{-1}. If 50% of eastern Australia's mulga lands (half of 25.4 million ha) were managed for C sequestration and biodiversity through the control of all herbivores, then annual sequestration rates could reach between 11.6 and 14 Mt CO_2-e year^{-1} which is between 2 and 2.5% of Australia's annual emissions. The potential to sequester carbon and improve biodiversity outcomes in extensive semi arid grazing lands will require significant policy shifts to encourage and reward necessary land use change.

1. Introduction

The search for potential terrestrial carbon (C) biosequestration options has focused primarily on forested landscapes or those landscapes with the potential for reafforestation. These lands tend to be located where higher and more reliable rainfall occurs. However, the potential of extensive areas of semi-arid and arid rangelands to sequester C has been receiving increasing attention because of the very large global extent of such environments (Glenn et al., 1993; Conant et al., 2001; Howden et al., 2001; Moore et al., 2001; Burrows et al., 2002; Dener et al., 2006; Harper et al., 2007; Wentworth Group of Concerned Scientists 2009). Although the current C content of semi-arid soils is low (usually around 1% or less by mass) relative to higher rainfall areas, the biosequestration potential of small increases over many millions of hectares is significant. For example, potential C sequestration in semi-arid soils of the United States has been estimated to be between 0.37 and 1.01 t CO_2-e ha^{-1} year^{-1}(Schuman et al., 2002) with up to 185 Mt CO_2-e year^{-1} for the whole US (Lal, 2004), achieved through the use of grazing management and active restorative practices. For Australia, estimates range between 20 and 250 Mt CO_2-e year^{-1} for arid and semi-arid Australia based on an assumption of restoration (Garnaut, 2008; CSIRO, 2009). Although considerable research into the interactions between grazing management and soil carbon has been undertaken in countries such as the United States (e.g. Frank et al., 1995; Schuman et al., 1999, 2002), many countries such as Australia do not have sufficient data to inform policy in this area.

The surge of interest in potential terrestrial C sequestration has to some extent overshadowed the pre-existing environmental and economic issues of productivity loss, degradation and biodiversity loss from grazed semi-arid and arid rangelands. While it is possible, and apparently intuitive, that managing these lands for increased soil C will assist in the amelioration of degradation, the linkages between environmental outcomes and C sequestration have not

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been thoroughly investigated (Beeton, 2005; Bagchi and Ritchie, 2010). An understanding of potential trade-offs between, or mutual benefits to, C sequestration and biodiversity will be essential in any policy environment (Beeton et al., 2006, p. 75; Bennett et al., 2010).

Because many arid and semi-arid environments show signs of degradation or over-utilization (Reynolds et al., 2007), restoration is desirable, but is usually too costly relative to the economic value of the land (Patrick et al., 2009). Although there has been some estimation, modelling and speculation as to the possible capacity of these lands in Australia to sequester C (see Harper et al., 2007; Garnaut, 2008; CSIRO, 2009; Fensham and Guymer, 2009), little empirical data are available for Australia and the land management required to achieve positive C accumulation and biodiversity outcomes of any changes are not known.

It may be that desirable states for ecosystem and biodiversity restoration may not lead to increased soil C or alternatively that a high soil C status can only be achieved with a less desirable ecosystem state. For example, very dense regrowth of mulga (*Acacia aneura* F. Muell) and other woody species, which is common in many semi-arid woodlands and shrubland of eastern Australia, may result in relatively high above ground biomass and moderate to high soil C content but little ecosystem process or habitat value for rare and threatened species. This situation could also change the hydrological balance either positively (greater soil moisture availability) or negatively (reduced run off for downstream needs). Alternatively, a lower density of woody vegetation and high herbaceous biomass coverage may be desirable for biodiversity values, but with unknown C storage potential. Further layers of complexity are added when issues of total grazing pressure and fire management, and in the case of the mulga lands specifically, the practice of mulga fodder harvesting (Page et al., 2008) are taken into account (Beeton et al., 2006, p. 40).

An opportunity exists to determine relationships between C biosequestration and some attributes of biodiversity because of the presence of long-term grazing exclusion experiments established across the mulga lands of south western Queensland since the 1960s. The mulga lands are representative of many of the environmental issues facing rangelands in general, and they have been subject to a reasonable level of formal research over many decades (Page et al., 2008). The grazing exclusion research since the 1960s replicates the effects of reduced or negligible grazing, with individual sites established for periods ranging from 13 to more than 40 years. This study does not aim to determine, nor does it assume what the pre-European vegetation state would have been, due to the variable and modified nature of ecosystems in the mulga lands (see Witt and Beeton, 1995; Witt et al., 2006, 2009). The outcomes from, and implications of, these exclusion studies have remained poorly reported with very few peer reviewed publications available. The result has tended to be that many of these exclosures have remained unmonitored, and at risk of deterioration and loss from the collective research consciousness.

The purpose of this study is to harness the ecological information from a sample of long-term grazing exclusion experiments to explore the impact of reduced grazing pressure on woody biomass, floristic biodiversity and soil C as well as to identify any synergies between them.

2. Methods

2.1. Study area

This study was conducted in the mulga (*Acacia aneura*) lands bioregion (Sattler and Williams, 1999, Fig. 1) in south west Queensland, Australia, which covers approximately three quarters of the mulga lands of eastern Australia. Although no sites were investigated in New South Wales, the ecosystems in Queensland are also largely representative of those occurring in north-west New South Wales. The region has a semi-arid climate with average annual rainfall ranging from almost 500 mm in the east to 150 mm in the west. Rainfall is highly variable with extended periods of below average rainfall punctuated by occasional short periods of above average rainfall. Temperatures are very warm to hot in the summer months (average maximum January temperatures above 36 °C) with cool winters (average minimum temperatures in July less than 6 °C), frosts are rare in the region.

The soils of the region range from red and brown loams (Kandosols) and texture contrast soils (Chromosols) to siliceous sands (Tenosols) in the uplands, with grey and brown cracking clays (Vertosols) dominating the alluvial areas; details of soils and geomorphology are available from Dawson and Ahern (1974) and Ahern and Mills (1990). The vegetation is dominated by woody plants (trees and shrubs) and plant association ranges are strongly linked to the geology and soil characteristics. Much of the vegetation is open to tall shrublands, open woodlands and woodlands that are generally dominated by mulga, with *Eucalyptus* (particularly *E. populnea* and *E. melanophloia*) becoming more dominant in the east. Some *Eucalyptus* species dominate the vegetation in places such as riparian systems, flood plains or other run on areas (Neldner, 1984). Most of the region is not suited to crops and the bulk of the land is used for sheep and cattle grazing with individual enterprises ranging typically between 35,000 and 65,000 ha in the central and eastern areas and over 100,000 ha in the west.

Grazing in the area was initially restricted to drainage lines and was subsequently massively extended by the tapping of artesian water (Gasteen, 1986), which permitted increased domestic grazing pressure as well as numbers and grazing pressure of kangaroos. The consequence was unquantified, but undoubtedly significant loss of above and below ground biomass and C. Rabbits reached the area in the 1890s and up to the 1950s had a significant impact on vegetation.

2.2. Field site descriptions

Nine grazing exclosures were sampled across the region (Fig. 1). The exclosures were erected between 1966 and 1996, with average size of approximately 2000 m^2 and were originally used for a range of experiments involving stock removal and thinning of woody vegetation (see Table 1 for overview). Monitoring in all of these exclosures had ceased prior to our study with the exception of one site (Wallen 5). All exclude domestic stock with some designed to exclude all native and feral grazing animals. Sites were sampled during two field trips on the 8–27 May and 10–30 June 2009. This had implications for some results as rain fell across parts of the region between the two sample periods.

Information on exclosures was retrieved from the Queensland Herbarium, communication with ex-managers and various researchers. Time and resource constraints limited the number of exclosures used in this study to 9 sites with selection based on the criteria of wide spatial and temporal (i.e. time since construction of the exclosure) distribution of the exclosures and that they were located in mulga dominated land systems.

The Currawinya and Mariala sites are located on what are now national parks that have had domesticated cattle and sheep removed. Both sites were previously grazing enterprises since approximately the 1860s. Mariala was gazetted as a national park before 1982 and Currawinaya in 1992. However, feral (predominantly goats) and native (red and grey kangaroos) herbivores are still present to such an extent that they exert considerable grazing pressure (Page, 1997). All other sites have been subject to continuous grazing.