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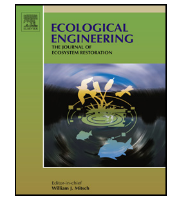

Optimising carbon sequestration in arid and semiarid rangelands

Christopher Dean [a,b,*], Jamie B. Kirkpatrick [a], Richard J. Harper [c], David J. Eldridge [b]

[a] Discipline of Geography and Spatial Science, School of Land and Food, University of Tasmania, Sandy Bay, TAS 7005, Australia
[b] School of Biological, Earth and Environmental Sciences, University of NSW, Sydney, NSW 2052, Australia
[c] Veterinary and Life Sciences, Murdoch University, Murdoch, WA 6150, Australia

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ABSTRACT

Destocking degraded rangeland can potentially help climate change mitigation by re-sequestering emitted carbon. Broad-scale implementation has been limited by uncertainties in the magnitude, duration and location of sequestration and the profitability relative to the existing grazing land use. This paper employs a novel methodology to assess potential rangeland sequestration and its profitability, using 31 Mha of rangeland in New South Wales, Australia as a case-study. This approach combines remotely sensed data and modelled estimates of various components. Remotely sensed, synthetic aperture radar data were used to determine woody biomass of minimally degraded forest (benchmarks) and neighbouring more-degraded forest, followed by sequestration modelling using non-linear growth rates based on woody thickening and slow-growing plantations, scaled to the benchmarks. Livestock concentration and livestock-based farm profits were modelled. We compared sequestration and grazing net profits, for a carbon price of AUD\$10 Mg^{-1} CO_2-e, at different growth stages for different levels of forest attrition. We found that broad-scale destocking with subsequent C re-sequestration was initially unprofitable compared with grazing. However, after 50 years, with full costing of C emissions, the returns were similar for the two alternatives of continued grazing or re-sequestration, for areas with biomass below benchmark levels. Reforestation of recently deforested land represents the most profitable option with profitability increasing with growth rate. Emissions of soil organic carbon, set in motion by climate change over the next century, were calculated to be the largest of all sources. Emissions from biomass, induced by climate change, will be higher where vegetation cannot adapt. The secondary effects of climate change will reduce re-sequestration and grazing profits, possibly limiting the carbon stored by re-sequestration projects.

1. Introduction

Rangelands supporting commercial livestock grazing are contested ground in which production of meat and other animal products for the increasing human population, nature conservation and conserving or replenishing carbon stocks increasingly compete for space (e.g. Glenn et al., 1993; Schuman et al., 2002; Reid et al., 2004; Dutilly-Diane et al., 2006; Khan and Hanjra, 2009; Janzen, 2011). These rangelands have commonly experienced net vegetation and soil loss (e.g. Allen, 1983; Fanning, 1999; Zucca et al., 2010; Dotterweich, 2013) corresponding to net C (carbon) emission. Reversal of land degradation linked to that carbon emission process can theoretically replenish the lost C (Howden et al., 1991; McKeon et al., 1992; Glenn et al., 1993; Walker and Steffen, 1993; Henry et al., 2002). The refilling of that depleted carbon stock (henceforth termed re-sequestration) contrasts with sequestration projects storing C in a form or location different to its origin (e.g. afforestation or power-station carbon capture and storage). Uncertainties in the potential magnitude, duration, location and profitability of carbon re-sequestration projects, have limited their implementation.

Rangeland emissions can be lessened by reduced deforestation, protection and enhancement of soil organic carbon (SOC), and by reforestation (Henry et al., 2002). Reforestation can be intensively managed (e.g. plantings), or passive/'natural' (e.g. Rey Benayas et al., 2007; Grainger, 2009) by allowing woody thickening (i.e. infill, Rackham (1998)) and regrowth to mature. The passive type is considered here, though managed reforestation can be used if finances permit. SOC stocks are generally positively correlated with aboveground biomass (Jackson and Ash 1998; Harms et al., 2005; Young et al., 2005; Wynn et al., 2006), being primarily

* Corresponding author at: University of Tasmania, Discipline of Geography and Spatial Science, School of Land and Food, Sandy Bay, TAS 7005, Australia. Tel.: +61 8 8651 2261.
E-mail addresses: cdeanspace@gmail.com, christopher.dean@utas.edu.au, christopher.dean@unsw.edu.au (C. Dean).

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derived from root turnover and litterfall. This relationship accounts for some of the decline in SOC stocks with vegetation attrition (Dean et al., 2012a), the remainder being through erosion pathways (Dean et al., 2012b). Magnitudes of change in soil organic carbon (ΔSOC) have higher uncertainty than associated changes in rangeland biomass (Henry et al., 2002). Consequently the present work focuses on biomass but with discussion of linked ΔSOC.

Rangeland C re-sequestration opportunities coincide with overgrazing or deforestation. Localised benchmarks of potential C stocks can be derived from remnant ecosystems or spatially dependent environmental variables (Greve et al., 2013). This equates to determining 'carbon carrying capacity' (Roxburgh et al., 2006). The potential of plantations to replenish C on deforested semiarid to mesic arable land in southern Australia was estimated by Paterson and Bryan (2012). Our work is thematically similar, but we use a finer spatial scale, simulate natural (autonomous, unmanaged) regrowth, allow a longer duration, and to reflect the higher error margins in rangeland, we calculate at a coarser economic scale.

Remote-sensing calibrated by ground-truthing, or, more frequently, ground-based assessments alone, are employed in rangelands for regular land condition assessments and woody biomass monitoring. Adaptation of remote-sensing technology is slowly approaching a level suitable for routine operational usage over the large expanses for which it was originally intended (e.g. Graetz et al., 1976; Mackay and Zietsman, 1996; Ustin et al., 2009). Both LANDSAT and the Advanced Land Observing Satellite (ALOS), phased array L-band synthetic aperture radar (PALSAR) sensor have proven applicability for aboveground biomass assessment of arid and semiarid open woodland (Armston et al., 2010; Lucas et al., 2010) with radar more sensitive to woody biomass and LANDSAT more sensitive to vertical foliage distribution (Armston et al., 2009; Danaher et al., 2010). PALSAR has proven applicability for carbon flux assessment in complex situations, though the basic radar data are often integrated with other data types, such as LiDAR or LANDSAT, or undergo more complex processing (e.g. Carreiras et al., 2012; He et al., 2012; Sarker et al., 2012). Here we principally use pre-processed data from PALSAR, and compare results with those from the lower resolution NOAA-AVHRR sensor.

Managed reforestation, including rehabilitation of degraded rangeland to enable woody regrowth where there has been substantial top soil loss, may require financial inputs (Spooner et al., 2002; Sparrow et al., 2003; Mengistu et al., 2005; Neff et al., 2005; Polglase et al., 2013). No financial inputs would be necessary if a low C sequestration rate, similar to that for passive reforestation of degraded and grassy areas by natural regrowth and 'woody thickening', can be applied.

Our main aims in this paper are to determine the most lucrative places in rangeland for C re-sequestration, and to develop a method for determining the C re-sequestration potential and rates for those areas. We apply this to rangeland in New South Wales (NSW) Australia, which is used largely for the generation of profit from grazing domestic livestock (henceforth termed commercial rangeland). An understanding of the relevance of our findings to rangeland outside of the study area is facilitated by a global climate and biome comparison. We discuss options for avoidance of any carbon emissions leakage after destocking. We use a notional carbon price for comparative purposes, fully realising that there is a long way to go before markets for carbon and rules for accessing such markets gain widespread acceptance.

2. Methods

2.1. Terminology and definitions

The boundary of the Australian rangeland zone has been variously mapped (Donohue et al., 2005). The definition for rangeland that we adopt is areas where domestic livestock 'rove at large' (Chambers, 1908) in natural or semi-natural vegetation inhospitable to arable agriculture — a subset of the 661 Mha rangeland zone of Donohue et al. (2005). After exclusion of reserves and non-pastoral uses, the remaining 369 (±5) Mha is commercial rangeland (Dean et al., 2012b).

The definition of forest we use is that of the Australian Government (DCCEE, 2010): a stand of trees covering at least 0.2 ha, attaining at least 2 m high at maturity and with at least 20% projected canopy cover. A projected canopy cover of 20% corresponds to approximately 11% foliage projected cover — a threshold used to delineate forest cover by remote-sensing (Scarth

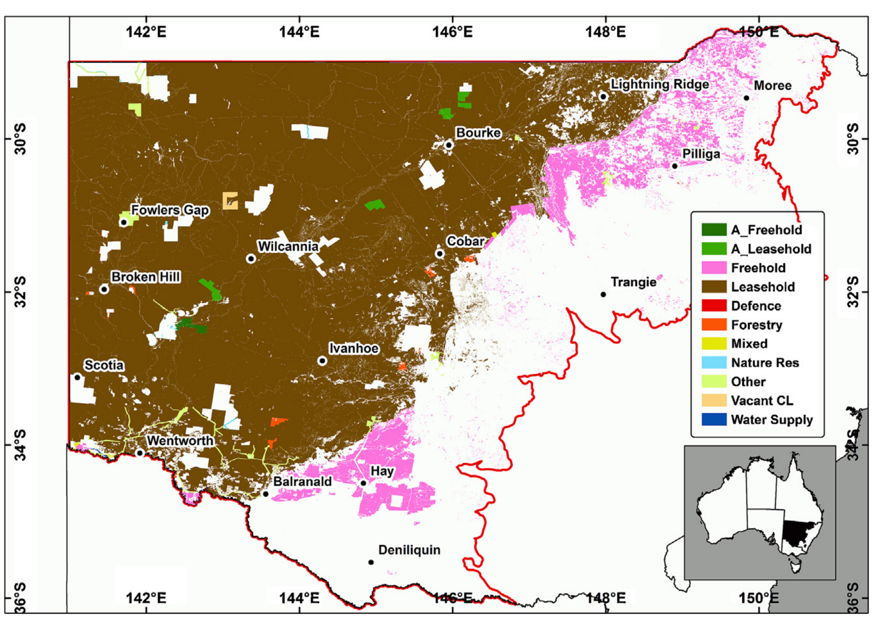

Fig. 1. Distribution of land tenure in the NSW commercially grazed rangelands. Rangeland zone boundary = red line. Abbreviations: 'A': Aboriginal, 'CL': crown land, 'Res': reserve, 'Mixed': multiple-use public land. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).