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Research Paper

Mitigation of carbon using *Atriplex nummularia* revegetation

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ABSTRACT

The use of abandoned or marginally productive land to mitigate greenhouse gas emissions may avoid competition with food and water production. *Atriplex nummularia* Lindl. is a perennial shrub commonly established for livestock forage on saline land, however, its potential for carbon mitigation has not been systematically evaluated. Similarly, although revegetation is an allowable activity to mitigate carbon within Article 3.4 of the United Nations Framework Convention on Climate Change's Kyoto Protocol, there is a paucity of information on rates of carbon mitigation in soils and biomass through this mechanism. For six sites where *A. nummularia* had been established across southern Australia four were used to assess changes in soil carbon storage and four were used to develop biomass carbon sequestration estimates. A generalised allometric equation for above and below ground biomass was developed, with a simple crown volume index explaining 81% of the variation in total biomass. There were no significant differences in soil organic carbon storage to 0.3 m or 2 m depth compared to existing agricultural land-use. Between 2.2 and 8.3 Mg C ha^{-1} or 0.2–0.6 Mg C ha^{-1} yr^{-1} was sequestered in above and below ground biomass and this translates to potential total sequestration of 1.1–3.6 Tg C yr^{-1} on saline land across Australia. Carbon income and forage grazing may thus provide a means to finance the stabilization of compromised land.

1. Introduction

Carbon dioxide (CO_2) levels have increased by 40% since pre-industrial times, and as a consequence global surface and ocean surface temperatures show a warming of 0.85 °C over the period of 1880–2012 (IPCC 2013). The increase in atmospheric CO_2 has mainly occurred through the combustion of fossil fuels and the conversion of forests to agriculture (Battle et al., 2000; Le Quéré et al., 2013). Across different emission scenarios the mean global surface temperature is projected to increase by between 1.5 °C and 3 °C relative to 1850–1900 by the end of the 21 st century (IPCC 2013).

A diverse range of policies, instruments and technologies are required to create a significant reduction in greenhouse gas (GHG) emissions and thus reduce the rate of temperature increase (IPCC 2014). The land sector both emits GHGs but also plays a central role in their mitigation (Bustamante et al., 2014; Smith et al., 2014). There are three main land sector approaches to mitigation: (1) the production of bioenergy from biomass to offset fossil fuel use (Chum et al., 2011), (2) carbon sequestration which is the transfer of atmospheric carbon dioxide into long-lived carbon pools in soils and plants (Lal 2008) and (3) the reduction in emissions from sources including deforestation, enteric fermentation in domestic animals and nitrogen fertilizers (Smith et al., 2014). Most research on land-based carbon mitigation has explored bio-sequestration via reforestation/afforestation, or storage in soils (Smith et al., 2014). Revegetation, which is the establishment of vegetation that does not meet the definition of a forest, is an allowable activity under Article 3.4 of the Kyoto Protocol (UNFCCC 1997), but is characterized by a lack of literature that quantifies its potential contribution to climate change mitigation (Smith et al., 2014).

Carbon sequestration is often viewed as a win–win situation, providing environmental co-benefits while also mitigating atmospheric CO_2 (Harper et al., 2007; Bustamante et al., 2014). However,

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Table 1
Summary of environmental features and sampling regime at each of the sites.

Site	Location		Planting Density	Rainfall	Salinity	Age of plantation	Number of plants sampled		Sampling methods	
	Lat. (°S)	Long. (°E)	(plants ha^{-1})	(mm)	(mS m^{-1})	(years)	AGB	BGB	AGB	BGB
Deniliquin	35.293	144.452	1250	337	–	5	14	14	F.H	Excavation + Cores
Monarto	35.717	139.848	1111	368	33	4	12	6	F.H	Excavation
Pithara	30.363	116.729	1411	315	192	11	14	0	F.H	–
Three Springs	29.622	115.649	892	382	288	13	12	0	F.H	–
Waikerie	32.433	117.394	635	248	23	4	9	9	F.H	Excavation
Wickepin	32.433	117.394	500, 2000	404	190	13	54	22	F.H	Excavation

Salinity measured with EM38; AGB: Above Ground Biomass; BGB: Below Ground Biomass; F.H: Full harvest.

concerns have been raised with respect to reforestation and competition for land (Haberl et al., 2014), water (Jackson et al., 2005), reduced biodiversity (Lindenmayer et al., 2012) and the displacement of other land uses (Mitchell et al., 2012). This increases pressure on food security, and may be most pronounced in developing countries where food shortages are more prevalent (Foley et al., 2005; Smith et al., 2014).

Utilising abandoned or degraded land for carbon mitigation provides an opportunity to utilise land that has marginal potential for other uses (Silver et al., 2000; Sochacki et al., 2012; Wicke et al., 2011). Campbell et al. (2008) estimated that 385–472 million hectares of land is abandoned globally and suggested that potential mitigation on abandoned land is greatest in Australia, Brazil, and the United States. Prolonged inappropriate agricultural practices are a common cause of land degradation (Powlson et al., 2011) and Australia has large areas of land that are abandoned because of improper farming practices, such as over clearing and overgrazing (Pannell and Ewing 2006). For example, large expanses of land have become saline, reducing the productivity of the affected land (Lefroy and Stirzaker 1999). It is estimated that 5.7 Mha of land across Australia has salinized or is at risk of becoming saline, with this increasing to 17 Mha by 2050 (National Land and Water Resources Audit, 2001).

A form of rehabilitation of saline land is the establishment of halophytic saltbush species (e.g. *Atriplex* spp.) (Smith 2008). These species are typically planted in areas of marginal value for cropping or grazing, because of their resistance to drought and tolerance of poor soil conditions (de Araújo et al., 2006; Slavich et al., 1999). *Atriplex nummularia* Lindl. is commonly used as forage for grazing ruminants during times of feed shortages, as peak foliage production occurs in summer when other feeds may be limited (Ben Salem et al., 2010). It follows that the majority of research involving this species has focussed on its use as livestock forage (Ben Salem et al., 2010; Glenn et al., 1998; Norman et al., 2004; Slavich et al., 1999).

The potential of *A. nummularia* established on abandoned and marginal agricultural land for carbon sequestration has not been formally published, despite the large amount of land potentially available for mitigation activities. The use of salt-land has however been considered for bioenergy production (Glenn et al., 1993; Sochacki et al., 2012; Wicke et al., 2011). Such a form of mitigation may be complementary to other forms of dryland carbon mitigation. Although mallee eucalypts are widely planted in Australian dryland carbon mitigation projects (Paul et al., 2015; Harper et al., 2017) these are not adapted to very saline soils.

Several assessments of the carbon mitigation potential of saltbush have remained in the grey literature (Issango et al., 2006; Montagu et al., 2003) or not been published at all. In this study, data from several of these studies and other unpublished data will be utilized, along with new field measurements. This study thus aims to explore the prospect of *A. nummularia* being used to sequester carbon on saline and poorly productive farmland in Australia by a) developing a more efficient method of estimating carbon in *A. nummularia* stands and in particular determining what explanatory variables contribute the most information to allometric relationships, b) producing an estimate of *A. nummularia* carbon sequestration potential at various sites across southern Australia, c) examining how carbon sequestered by *A. nummularia* is partitioned between soil organic carbon, and above and below ground biomass and d) examining factors such as planting density that affect the rates of sequestration by this species. This will allow policy makers, landholders and investors to determine whether carbon sequestration using this species is a viable carbon mitigation strategy, particularly in relation to other carbon mitigation approaches such as reforestation.

2. Methods

2.1. Sampling sites

Data were collected from six sites where *A. nummularia* had been established on farmland across southern Australia (Table 1, Fig. 1). These sites were considered representative of land that is marginal or degraded for typical agriculture in these areas. Across the six sites planting density varied from 500 to 2000 plants ha^{-1} and stand age ranged from 4 to 13 years at the time of sampling (Table 1).

The six sites all fell within the Australian temperate climate zone, using the Köppen classification system, with wet and mild winters, hot dry summers (BOM 2017) and mean annual rainfall ranging from 248 to 404 mm yr^{-1} (Table 1). The sites were grazed by sheep during late summer with edible dry matter (<2 mm stem size) removed. Plots were left to regrow and were measured in the following period, prior to grazing.

The sites were classified as saline or not saline based on soil measurements (Table 1). For Pithara, Three Springs and Wickepin a Geonics EM38 conductivity meter was used and for Monarto and Waikerie, salinity was measured on soil samples, and converted to EM38 equivalent values using the approach of McKenzie et al. (1989). No soil salinity data were available for Deniliquin.

2.2. Biomass sampling

The carbon mitigation potential of a planting is often calculated using allometric equations. These equations relate explanatory values such as height, crown width, or a crown volume index (CVI) to the above, below, or total biomass of a given individual plant. The use of these equations allows carbon mitigation to be calculated without the need for destructive sampling.

At each site saltbush plants were destructively sampled as described by Snowdon et al. (2002). Plants were randomly selected across the dynamic range of plant sizes to ensure data were representative. Potential predictor variables of shrub height, crown height, length and width were measured and applied in the development of allometric relationships. The number of plants sampled at each site is given in Table 1.