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Using Carbon Reforestation for Water and Environmental Restoration

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Abstract: A range of environmental problems including loss of biodiversity, desertification, and compromised water quality persist across many arid and semi-arid environments despite a good technical understanding of both the processes involved and likely solutions. Reforestation is an emerging method of carbon mitigation and this carbon investment may thus provide a means of addressing these environmental problems and achieving landscape scale changes. A possible negative outcome of large scale land-use change may be depletion of food production. In south-western Australia several approaches have been used to integrate carbon mitigation with food production and to value the various environmental services (e.g. water quality and yield, carbon mitigation) produced from reforestation. This paper describes three case studies: (1) a large-scale commercial carbon reforestation scheme project which integrates strips of eucalypts with cereal farming, (2) reforestation of salinized and abandoned farmland and (3) watershed scale modeling that uses an existing hydrologic model to predict water yield and quality impacts of reforestation. Although reforestation is also likely to result in other environmental benefits these are often not valued. In contrast, where hydrologic models exist, these allow the valuation of water benefits. In the latter example, the value of several products of reforestation (wood, carbon, water) were assessed and compared to the value of products from the existing farming system.

Key Words: Biodiversity, Carbon mitigation, Payments for environmental services (PES), Salinity, Watershed management

1. Introduction

Several approaches can be taken to reduce overall carbon emissions, including increasing energy efficiency, replacement of fuel sources, renewable energy and land-use change (Pacala and Socolow, 2004). One form of land-use change is reforestation of farmland, and this can be used to achieve carbon mitigation, via either sequestration or the replacement of fossil fuels. Sequestration is encompassed in Article 3.3 of the Kyoto Protocol (Schlamadinger and Karjalainen 2000) and features as a activity in several national and voluntary emissions trading schemes.

There are several intractable environmental problems in semi-arid areas that can be managed through reforestation, including hydrologic imbalances resulting in salinization, soil erosion, biodiversity loss from overgrazing and deterioration of water quality. In many jurisdictions, there is insufficient capital to implement the changes that are necessary. The scale of future carbon mitigation investment may be large, and herein lies an opportunity to use carbon reforestation to tackle water and environmental problems at a landscape or regional scale (Harper *et al.* 2007). This analysis evaluated the economics of carbon sequestration and suggested it could take the form of forests established to restore landscape hydrology, windbreaks to control soil erosion, and plantings to enhance biodiversity and provide habitat for local fauna.

Two emerging issues however require specific consideration. The first is the potential for negative aspects of large-scale carbon reforestation, including the competition for farmland and thus food production. This replays some of the debates which have occurred in the past with reforestation and the reduction of water yields from watersheds (Calder, 2005). This discussion has been particularly strong in Australia (Mitchell and Harper 2011). One approach is to consider integrating trees into farming systems (Harper *et al., In Press*) so as to maintain both food production and achieve carbon mitigation, or to use abandoned or low value land (Sochacki *et al., In Press*).

A second issue is of valuing the co-benefits and drawbacks from reforestation. If reforestation achieves a range of outcomes, it can be argued that it is inequitable that only the carbon should be valued, and that the other benefits are not valued. Similarly, the costs of *not* undertaking restorative action can also be valued. An economic framework should provide a basis for rational decision making and payments for environmental services (PES) is a rapidly evolving area (Costanza *et al.*, 1997; Barbier, 2007).

In this study we describe the approaches to these problems – optimizing and valuing carbon mitigation, food production and water and environmental co-benefits – that have been developed in Western Australia (WA). This region is characterized by

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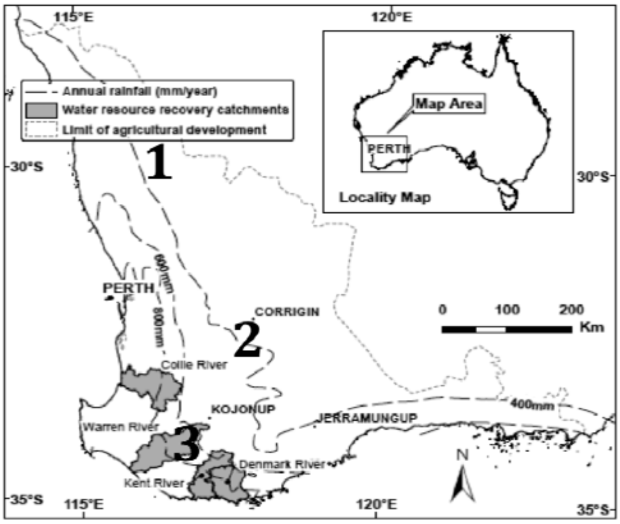

Fig. 1. Location of the three case study sites (1-3) across the south-west of Western Australia.

infertile soils, a Mediterranean climate and the accumulation of salts within deep regolithic profiles. In this region, extensive development of land occurred in the period 1950-1980, with this involving the removal of natural eucalypt dominated vegetation and its replacement with dryland farming systems. These involve cereal cropping (wheat, barley) usually in rotation with grazing systems of annual legume based pastures (Burvill, 1979). An extensive range of land degradation problems have developed, including salinization as a result of an induced hydrologic imbalance (Peck and Hatton 2002), wind erosion (Harper *et al.*, 2010), and biodiversity loss (Myers *et al.*, 2000). The approaches developed here are applicable to other semi-arid areas in the world.

2. Methods

Three case studies are examined. These occur within three distinct areas of the agricultural zone of WA (**Fig. 1**).

2.1. Case study 1 - Carbon mitigation using agroforestry strips.

One approach to achieving both hydrological benefits and carbon sequestration is to establish strips of trees across the landscape, with the continuation of food production, in this case cropping, between the tree strips. Several short stature eucalyptus species, termed mallees, are used in a system that was initially developed to provide a means for the hydrological management of salinity (Robinson *et al.*, 2006).

Kansai Electric Power Company engaged KANSO Technos to undertake a reforestation project through the Oil Mallee Company of Australia as an agent in the Kalannie region of WA (Fig. 1). This project has involved the establishment of 10-20 m wide strips of mallee eucalypts interspersed with cereal cropping of varying widths in an area with around 300 mm/year annual rainfall. The aims of the reforestation have been to abate greenhouse gas emissions through sequestering carbon in long-term (>30 years) environmental plantings.

Three species of mallee eucalypts (*E. kochii* spp. *plenissima*, *E. loxophleba* spp. *lissolphloia*, *E. horistes*) were established in June 2003 across 30 discrete farms, with 893 ha in total. Trees were measured in June 2010 using permanent forest sampling plots. Tree attributes measured included height and diameter of stems. Biomass and sequestered carbon were estimated from proprietary allometric equations.

2.2. Case study 2 - Carbon mitigation and repair of abandoned land.

Large areas (potentially over one million hectares) of land have become salinized across the region, and the land is no longer used for agricultural purposes. This project involved the establishment of several salt-tolerant species on a salinized area near Wickepin (Fig. 1). The aims of this reforestation have again been to achieve carbon mitigation via either carbon sequestration or the production of biomass for co-firing for electricity production, and the stabilization of soils and hydrology in the salinized area (Sochacki *et al.*, *In Press*). However, it is considered unlikely that such reforestation will restore hydrology (George *et al.*, 1999).

2.3. Case study 3 - Carbon mitigation combined with improved water quality.

The impact of reforestation on water supplies is often considered in terms of impacts on water yield. In specific circumstances, such as the restoration of salinity, reforestation will improve water quality to the extent that previously unusable water can be utilized.

The study (Townsend *et al.*, *In Press*) used as an example the Warren-Tone, a large (408 000 ha) agricultural watershed with between 500 to 700 mm/year annual rainfall. Around a quarter of this catchment (105 000 ha) had been previously cleared, with 25 000 ha subsequently reforested with pulpwood (*Eucalyptus globulus*) plantations. Water yield and quality outcomes of various reforestation scenarios were estimated using LUCICAT a calibrated hydrological model (Bari and Smettem, 2006). A hydrological-land -use-economic model was constructed, and as described in Townsend *et al.* (*In Press*), this allows the costs and benefits of different land-uses to be examined at a whole watershed level. This bundled payments for various environmental

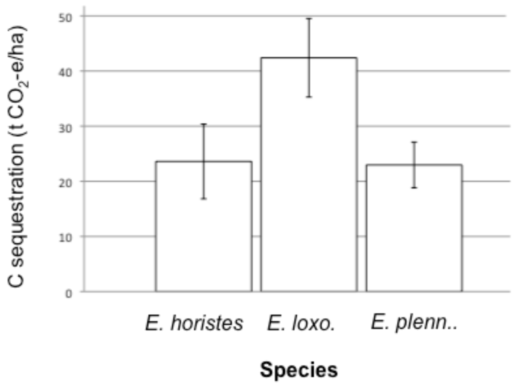

Fig. 2. Mean carbon sequestration (t CO_2-e/ha) of the three eucalypt mallee species after 7 years of growth at Kalannie (Case study 1)

services (PES), and externalities, following reforestation. These included estimates of returns from water, wood and carbon and comparisons with the existing agricultural production.

3. Results and Discussion

3.1. Case study 1 - Carbon mitigation using agroforestry strips.

The mean tree height at seven years across all plots was 2.06 m, this exceeding the forest eligibility requirement of Kyoto compliant forests. The average current stocking was 1709 trees/ha, down from the mean original stocking of 2 378 trees/ha. Mean biomass across all sites was 14.9 dry t/ha, and estimated carbon sequestration 27.3 t CO_2-e/ha.

There was marked variation in the mean performance of the different eucalypt species, with *E. loxophleba* spp. *lissolphloia* having a mean yield across all sites of 42.4 ± 0.7 t CO_2-e/ha, compared to values of 23.6 ± 0.7 t CO_2-e/ha and 23.0 ± 0.3 t CO_2-e/ha for *E. kochii* spp. *plenissima* and *E. horistes*, respectively (**Fig. 2**). There were also marked differences in both biomass accumulation (0.1 - 42.9 dry t/ha) and carbon sequestration across sites (range 0.1 - 78.7 t CO_2-e/ha). This style of reforestation is relatively new and these results suggest that further exploration of the different rates of sequestration between species and with site conditions will be profitable, particularly as these aspects can be managed.

3.2. Case study 2 - Carbon mitigation and repair of abandoned land.

A range of factors significantly affected both carbon sequestration and biomass production on the salinized site (Sochacki *et al.*, *In Press*). These include hydrological conditions such as salinity, site factors such as slope position and soil properties and a range of silvicultural factors such as

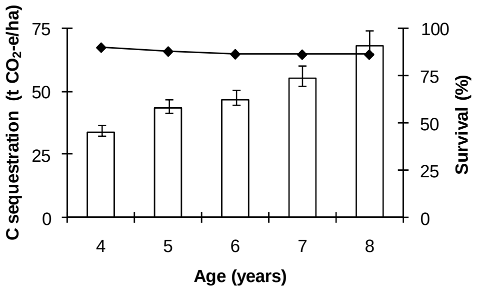

Fig. 3. Mean carbon sequestration (t CO_2-e/ha) of *Eucalyptus occidentalis* planted at 2,000 trees/ha at Wickepin (Case study 2).

species, planting density and age of the planting. High density (2,000 trees/ha) plantings of *Eucalyptus occidentalis* produced a mean of 37 t/ha of dry biomass (equivalent to 68 t CO_2-e/ha), eight years after planting (**Fig. 3**). Continued mitigation is expected as the stands mature, assuming that growth is not affected by the accumulation of salt in the soil profile (Archibald *et al*., 2006).

The same principle of using reforestation to both achieve carbon mitigation and land repair also applies to lands that have been damaged by erosion, over-irrigation or contaminated by pesticides; utilization of such land could thus represent a major contribution to global carbon mitigation without competing with food production.

3.3 Case study 3 - Carbon mitigation combined with improved water quality.

A hydrological model (LUCICAT) was used to define the relationships between reforestation/deforestation and water yield and quality, thus providing a basis for valuing the hydrological benefits of reforestation. Various land-use change scenarios were examined, with these suggesting that 70% reforestation was required to restore stream salinity to a potable threshold of 500 mg/L total dissolved salts (TDS) (Townsend *et al.*, In press). Although it was estimated that this would reduce annual water yields from 260 GL/year to 237 GL/year, a response reported in other watersheds, the important distinction here is that water would be restored to a potable condition and thus have value. Economic modeling suggested that the sale of 100 GL/year of water at AUD$150,000/GL would result in a net water value of $285/ha/year.

Reforestation was unprofitable when only wood revenues from reforestation were considered, with a discount rate of 9.5% but was profitable at lower discount rates and with carbon prices of at least $26 t CO_2-e. Additional income would come from the sale of timber and carbon, and the bundled return from timber, carbon and water is more

Table 1. Agricultural returns and externalities and forestry returns from both timber and carbon (AUD$/ha/year) in the Warren Tone watershed (Case study 3). Net Present Values were calculated with a discount rate of 7%.

Returns ($/ha/year)	Annual rainfall (mm/year)	
	500	700
Agricultural returns	150	190
Externality (salinity) costs of agriculture	-50	-30
Net value of agriculture	100	160
Timber return	-200	-113
Carbon return	354	357
Water return	285	285
Timber + carbon + water	439	529
Net benefit of forestry over agriculture	339	369

profitable than the existing agricultural system (**Table 1**).
The sale of potable water following reforestation could provide a new source of income for landholders, on the proviso that there is enough reforestation across the watershed to reach the potable threshold.

4. Conclusions

Whereas carbon reforestation can provide carbon mitigation, different approaches such as using strips of trees or abandoned land, may allow integration with existing agriculture. This reforestation is also likely to result in other environmental benefits. There also appears to be considerable potential to increase the efficiency of mitigation via species and site selection and silvicultural practices.

Environmental benefits are often not brought to account, mainly because of difficulties of valuing land repair and biodiversity restoration. Both represent a future challenge. In contrast, where hydrological models exist, these provide a means of valuing potable water benefits both within specific watersheds but also as a tool to evaluate different policy options.

Bundling of the multiple environmental outcomes of reforestation also appears promising; in this case markets are required for each of the bundled components. Importantly, the carbon mitigation debate is often framed in terms of impacts on food production, whereas water and fiber are also essential commodities that are produced from the land.

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