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Hotspots of threat and opportunity from widespread reforestation for carbon offsets

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Abstract: The demand for carbon permits is expected to increase rapidly with the introduction in Australia of the Carbon Pollution Reduction Scheme (CPRS) in 2010. The CPRS will cap the emission of greenhouse gasses and create a market for carbon trading. Some prediction of the behaviour and impacts of the emerging market will inform potential policy responses. Introduction of a carbon market could result in strong demand for widespread conversion of land in agricultural regions to tree-based production of carbon permits which may pose a number of threats and opportunities for Australia's biodiversity, water resources, and rural environments and communities. This study aimed to quantify the potential generation of carbon permits from reforestation following the CPRS, and the potential conflicts this may cause. Carbon price was considered the main driver of adoption and this study does not consider other factors that may influence adoption. Specific focus was on the Mediterranean-type agricultural landscapes in South Australia.

The potential distribution of the supply carbon permits from reforestation in South Australia's agricultural regions was modelled within a Geographic Information System (GIS). Spatio-temporal and economic models of tree growth and productivity, and agricultural profitability were used to estimate the viability of reforestation for carbon permits under various carbon price scenarios. Low diversity monocultures and high diversity native species were considered. Biodiversity conservation values were modelled spatially using a series of landscape ecology metrics and conservation planning principles. Spatially explicit water resource management priorities were modelled based on soil landscape characteristics. The impact on water yields from carbon-driven reforestation was modelled using Zhang curves. The location of threats and opportunities associated with the production of carbon permits were identified and then coupled with economically viable areas for carbon reforestation to identify hotspots where there is high potential for carbon supply that either complements or conflicts with biodiversity and water management goals.

The results of this study found that reforestation for the supply of carbon permits under the CPRS may be more profitable than agricultural production over significant proportions of South Australia's agricultural landscapes, depending on future carbon prices. For example, it would be economically viable to reforest approximately 5.3 million ha (50%) of the study area if the carbon price was \$20/t of CO_2^{-e}. Whilst reforestation using a diverse mix of native species was viable over 4 million ha at \$20/t it could potentially cover over 40% of the high priority biodiversity conservation locations. However, significant threats are posed to zones of high priority biodiversity conservation value and high yield water run-off and aquifer recharge. The conversion of shallow-rooted annual cropping systems to deep-rooted tree-based monocultures uses more water and provides minimal biodiversity value. Approximately 1,200 GL would potentially be unavailable for surface and groundwater storage in catchments supplying a large proportion of the South Australian population if the carbon price is \$20/t of CO_2^{-e}.

Various policy options are available to ensure reforestation is steered toward tree species that provide biodiversity benefits (e.g. mixed planting of species with local provenance). For example, a payment for ecosystem services (biodiversity) could be paid to land owners to compensate for the difference in income from the sale of permits generated by high yielding low diversity plantings against the lower yielding diverse plantings. This study suggests those payments would have to be in the order of only \$5/ha/yr if carbon price is \$20/t of CO_2^{-e}, but up to \$115/ha/yr if carbon price is \$45/t. Regulatory measures could be applied in locations where reforestation threatens aquatic ecosystems and the availability of water resources. Similarly, hotspots could be zoned where monocultures provide high opportunity and no threat to ecosystems.

Keywords: *Emissions Trading Scheme; biosequestration; spatial analysis; economic analysis; natural capital and ecosystem services.*

1. INTRODUCTION

The Australian Government, as a recent signatory to the Kyoto Protocol, aims to reduce its greenhouse gas emissions through the introduction of the Carbon Pollution Reduction Scheme (CPRS) in 2010. The sequestration of atmospheric carbon dioxide through reforestation holds much promise for mitigating the impact of climate change and qualifies for carbon permits (Australian Government, 2008). An activity that The Australian Government (2008) expects that most reforestation established under the CPRS will be non-harvest permanent plantings on less productive land. Recent studies have demonstrated that reforestation using permanent plantings for generation of carbon permits is a viable proposition in Australia's agricultural landscapes (Lawson et al., 2008; Polglase et al., 2008). Lawson et al. (2008) estimate that approximately 5.8 million hectares of Australia's agricultural land is viable for reforestation under a carbon price of \$20.88/t CO_2^{-e}, half of which could be permanent plantings. The viable area increases to 26 million hectares under a carbon price of \$29.20/t CO_2^{-e}, approximately 83% of which could be permanent plantings. Polglase et al. (2008) estimate that 9 million hectares of permanent reforestation plantings is viable in Australia under a carbon price of \$20 CO_2^{-e}.

The widespread uptake of permanent reforestation plantings for carbon sequestration provides significant opportunities for the restoration of natural capital degraded by agriculture (Tilman et al., 2001). Reforestation of cleared landscapes under a permanent planting management regime can mitigate soil erosion, improve water quality and mitigate salinity caused by rising water tables (Hobbs et al., 1993; Benyon et al., 2006). The chances for conservation and enhancement of biodiversity improve if reforestation consists of a mixture of local indigenous species (Salt et al., 2004). However, reforestation also poses several threats to stocks of natural capital if poorly located. Increased trees in a catchment can reduce surface water runoff (Zhang et al., 2001) and groundwater recharge (Benyon et al., 2006), resulting in lower yields for human use and threats to aquatic ecosystems. Permanent plantings of low diversity or exotic tree species provide little benefit for biodiversity and may threaten biodiversity (Sayer et al., 2004).

Recent attention has focused on the potential win-win outcomes from carbon-motivated reforestation and the provision of ecosystem services derived from expanding the stocks of natural capital (Bekessy and Wintle, 2008; Hunt, 2008; Nelson et al., 2008). For example, payment for the provision of ecosystem services (PES) is a policy instrument of increasing interest (Wunder et al., 2008). A landowner could earn multiple incomes on a single tract of land by reforestation that sequesters carbon, establishes wetlands and improves biodiversity and water quality (Fox, 2008). However, rarely are the threats to natural capital sufficiently accounted for in carbon-motivated and PES reforestation programs.

The present study aims to identify the hotspots of win-win opportunities as well as the threats to natural capital from widespread carbon-motivated reforestation in the cleared agricultural landscape of South Australia. Multiple spatially explicit models are used to identify locations where: i) reforestation is viable given various carbon and crop and livestock commodity price scenarios; ii) reforestation using diverse locally native species would provide biodiversity benefits but low diversity species threatens biodiversity; iii) reforestation mitigates soil erosion and improves water quality, and; iv) surface and groundwater yields are threatened by reforestation.

2. METHODS

2.1. Study Area

The 15.8 million ha study area encompasses the agricultural districts of South Australia. Land use is dominated by grain cropping (31.6% of study area) and livestock grazing on either improved pasture or remnant vegetation (35.4%). Approximately 32.9% of native vegetation remains concentrated in the low rainfall northern and western parts of the study area. Climate in the study area is largely Meditterranean with average annual rainfall ranging from 250 mm in the dry northern parts of the study area to over 1,000 mm in central and southern parts.

2.2. Viability of Carbon Offsets

The net present value *NPV* (see Table 1 for notation) of carbon forest plantation was calculated across the study area as $NPV = PVB - PVC$ to a time horizon of 2050. *PVB* is the present value of the benefits and was calculated based on a range of carbon prices p_i where i = \$10/t, \$15/t, \$20/t, \$25/t, \$30/t and \$45/t. Annual carbon sequestration potential (q_{tj}) was modelled using 3-PG Spatial (Sands and Landsberg, 2002) under historical average climate for three permanent planting reforestation systems j where j = high yield

Eucalyptus globulus confined to >350mm annual precipitation; oil mallee species *Eucalyptus kochii*, and; a suite of mixed native species: .

$$PVB_{ij} = \sum_{t=0}^{T} \frac{p_i \times q_{tj}}{(1+r)^t} \tag{1}$$

PVC is the present value of the costs (including the opportunity costs associated with forgone agricultural production):

$$PVC = \sum_{t=0}^{T} \frac{EC_t + MC + OC}{(1+r)^t} \tag{2}$$

Whilst establishment (*EC*) and maintenance (*MC*) costs are uniform over the study area, the opportunity cost of forgone agricultural production (*OC*) varies spatially. Opportunity costs were calculated based on Bryan et al. in press). Production of the predominant cropping (wheat, field peas) and grazing (beef, sheep) land uses were modelled using APSIM with historical climate data and a soils database. The value of production was sourced from agricultural census data, and costs of production from gross margin handbooks (Table 1). An opportunity cost layer was calculated in a GIS based on land use mapping as:

$$OC = (P_1 \times Q_1 \times TRN) + (P_2 \times Q_2 \times Q_1) - (QC \times Q_1) + AC + FC \tag{3}$$

A total of 18 spatial layers were created quantifying the net present value of carbon forest plantation, one for each of the 6 carbon prices and 3 reforestation systems. Economically viable areas were identified for reforestation of cleared landscapes for of carbon sequestration where $NPV > 0$.

Table 1. Definitions and descriptions of symbols used in economic viability analysis of carbon.

Symbol	**Definition**	**Units**	**Description**
T	Number of years modelled	Years	Number of years from 2007 to 2050, $T = 41$
P	Price of carbon	\$/t CO2^{-e}	Modelled for six prices: \$10/t, \$15/t, \$20/t, \$25/t, \$30/t and \$45/t
q_i	Carbon sequestered	t/ha/yr CO2^{-e}	Modelled using spatially explicit 3-PG
R	Annual discount rate	%	Discount rate set at 7%
EC_t	Establishment costs	\$/ha	EC_t = \$2,000/ha for $t = 0$, 0 otherwise
MC	Maintenance and transaction costs	\$/ha/yr	Fixed at \$20/ha/yr
OC	Opportunity cost of agriculture	\$/ha/yr	Profit at full equity based on Bryan et al., 2008
I_A	Income from dryland agriculture	\$/ha/yr	See below
C_A	Costs of dryland agriculture	\$/ha/yr	See below
P_1	Price of primary product	\$/t or \$/DSE	Sourced from AgStats data (ABS, 2006) at SLA resolution
Q_1	Yield of primary product	t/ha or DSE/ha	Modelled using APSIM under long-term climate averages. (see Bryan et al., in press a)
TRN	Turn-off rate or proportion of herd sold	$0 \leq$ TRN ≤ 1 for livestock	Sourced from AgStats data (ABS, 2006)
P_2	Price of secondary product	\$/kg	Applies to wool. Sourced from AgStats data (ABS, 2006)
Q_2	Yield of secondary product	kg/DSE	Applies to wool. Sourced from AgStats data (ABS, 2006)
QC	Quantity dependent variable costs	\$/t or \$/DSE	Sourced from ABS (2006) and Rural Solutions (2008)
AC	Area dependent variable costs	\$/ha/yr	Sourced from ABS (2006) and Rural Solutions (2008)
FC	Fixed costs	\$/ha/yr	Operating, depreciation and labour costs sourced from ABS (2006) and Rural Solutions (2008)

2.3. Biodiversity Conservation Priorities from Reforestation

Spatially-explicit priorities for reforestation using diverse mix of locally indigenous species were identified using a series of spatial metrics drawn from established conservation planning (Margules and Sarkar, 2007) and landscape ecology (Turner and Gardner, 1991) principles. The logic is based on the premise that landscapes are heterogeneous and reforestation in certain locations will arguably contribute more to biodiversity conservation goals than in other locations (Malanson and Cramer, 1999). This is particularly the case in heavily fragmented and degraded landscapes such as the study area. Table 2 describes each metric modelled in this study.

Locations of high and low priority for reforestation to potentially improve biodiversity conservation were identified in a two stage process. Firstly, high priority remnant vegetation patches were identified using an additive function that combines all **remnant vegetation** metrics (Table 2). Each metric was rescaled to the range 1 (low priority) to 5 (high priority) before input into the vegetation priority (*VP*) function:

$$VP = P_A^{1-5} + P_S^{1-5} + P_{CO}^{1-5} + P_R^{1-5} + P_S^{1-5} + P_{CZ}^{1-5} \tag{4}$$

Remnant vegetation patches were considered high priority when $VP \geq \overline{VP}$ and these were used as input into and elements of the second stage (C_{DH} in Table 2). The second stage involved computation of another additive function that combines all **cleared landscape** metrics (Table 2). Each metric was rescaled to the range 1 (low priority) to 5 (high priority) before input into the biodiversity priority (*BP*) function:

$$BP = C_V^{1-5} + C_{DA}^{1-5} + C_{DH}^{1-5} + C_P^{1-5} + C_S^{1-5} + C_C^{1-5} \qquad (5)$$

The output is a spatial layer that scores every cleared location in the study area according to its biodiversity priority for reforestation using diverse mix of locally indigenous species. A location was consider high priority when $BP \geq \overline{BP}$.

Table 2. Description of metrics used to estimate spatially explicit priorities for biodiversity conservation.

Symbol	Metric	Description
Remnant Vegetation		
P_A	Patch Area	Total area of contiguous patches of remnant vegetation.
P_S	Patch Shape	An index of patch shape complexity calculated for all contiguous patches of remnant vegetation. Incorporates patch area (*A*) and perimeter (*P*). Values closer to 1 indicate lower shape complexity. Calculated as: $P_S = \frac{P}{2\sqrt{\text{pi}A}}$ (6)
P_{CO}	Patch Connectivity	An index of connectivity P_{CO} calculated as $P_{CO} = \sum_{j=1}^{J} A_j e^{-\bar{D}^{-1} d_{ij}}$ (7) Where *J* is the # of neighbouring patches, A_j is the area of patch *j*, d_{ij} is the Euclidean distance to patch *j*, and $\bar{D}$ is the mean dispersal distance to all neighbouring patches (see Vos et al., 2001).
P_R	Remnant Vegetation Protection	Percentage of each remnant vegetation community formally protected under a conservation agreement which includes NPWS reserves, Heritage Agreements, RAMSAR sites.
P_S	Soil Protection	Percentage of each vegetated Soil Landscape Unit formally protected under a conservation agreement.
P_{CZ}	Climate Protection	Percentage of each vegetated climate zone formally protected under a conservation agreement. Climate zones derived using methodology reported in Crossman and Bryan (2006).
Cleared Landscapes		
C_V	Veg. Fragmentation	Percentage remnant vegetation cover within 5km radius from every location in study area.
C_{DA}	Dispersal Distance - All	Euclidean distance (D) from all remnant vegetation rescaled using a negative exponential transformation. Locations closer to remnant vegetation have exponentially greater importance based on dispersal ecology theory (Willson, 1993). Calculated as: $C_{DA} = e^{\frac{-1}{1000D}}$ (8)
C_{DH}	Dispersal Distance – High Priority	Euclidean distance (D) from high priority remnant vegetation patches rescaled using a negative exponential transformation. High priority remnant vegetation defined from remnant vegetation metrics described above. Calculated using equation 8.
C_P	Pre-Euro Remnancy	Percentage of each pre-European vegetation class remaining under remnant vegetation.
C_S	Soil Remnancy	Percentage of each Soil Landscape Unit remaining under remnant vegetation.
C_C	Climate Remnancy	Percentage of each climate zone remaining under remnant vegetation. Climate zones derived using methodology reported in Crossman and Bryan (2006).

2.4. Soil and Water Management Priorities for Reforestation

Spatially explicit management priorities for soil and water were modelled using existing soil risk metrics contained in the South Australian Soil Landscape Unit database (DWLBC, 2007). This soil database classifies all soil in the study area according to wind erosion risk (S_{WI}), water erosion risk (S_{WA}), gully erosion risk (S_G), dryland salinity risk (S_S) and shallow water table risk (S_T). Highest risk areas will benefit most from reforestation and hence are highest priority for reforestation. Reforestation priority for soil and water was calculated using an additive function that combines these soil risk attributes. Each attribute was rescaled to the range 1 (low priority) to 5 (high priority) before input into the soil and water priority (*SWP*) function:

$$SWP = S_{WI}^{1-5} + S_{WA}^{1-5} + S_G^{1-5} + S_S^{1-5} + S_T^{1-5} \qquad (9)$$

The output is a spatial layer that scores every cleared location in the study area according to its soil and water management priority for reforestation. A location was consider high priority when $SWP \geq \overline{SWP}$.

A second spatially explicit water management layer was modelled to estimate the direct threats to surface and groundwater yields from reforestation. The scarcity of water resources has motivated the South Australian State Government to prescribe the use of water in certain locations in the study area. Reforestation activities impact of water yield through increased evapotranspiration (Zhang et al., 2001). Total evapotranspiration before and after reforestation was calculated for each management unit k within mapped prescribed water resource areas and south-east groundwater management areas (from Zhang et al., 2001):

$$ET_k = \left(f_k \frac{1+2820P_k^{-1}}{1+2820P_k^{-1}+\frac{P_k}{1410}} + (1-f_j)\frac{1+550P_k^{-1}}{1+550P_k^{-1}+\frac{P_k}{1100}} \right) P_k \qquad (10)$$

Where P_k is average annual rainfall and f_k is proportion of tree cover for each k, with f_k varying according to cover before and after reforestation. The change in evapotranspiration ΔET_k caused by reforestation was than calculated as $\Delta ET_k = ET_{Rk} - ET_{Vk}$ where ET_{Vk} and ET_{Rk} are total evapotranspiration before and after reforestation, respectively. The ΔET reforestation was converted to a volumetric measure of water.

2.5. Hotspots of Opportunity and Threat

Spatially-explicit opportunities and threats for reforestation for carbon vary according the reforestation system and the location of the biodiversity, water and soil management priorities. Threats occur when:

1) Reforestation using low diversity species occurs in high biodiversity priority locations.
2) Reforestation of any species occurs in important water yield locations.

Opportunities occur when:

1) Reforestation using high diversity indigenous species occurs in high biodiversity priority locations.
2) Reforestation of any species occurs in high soil and water management priority locations.

3. RESULTS

The area of reforestation for carbon that is an economically viable proposition in the cleared agricultural districts of South Australia increases significantly with carbon price (Figure 1a). At the low price of \$10/t CO_2^{-e}, approximately 600,000 ha are viable, regardless of species. As price increases, oil mallee becomes viable across a greater area than mixed native species or *E. globulus*. The area viable for *E. globulus* is less than the mixed native species even as price increases because productivity of *E. globulus* is zero under the large parts of the study area that receive low rainfall. The total Mt of CO_2^{-e} sequestered annually follows a similar pattern (Figure 1b), but *E. globulus* is more productive than mixed native species. Under the often-quoted carbon price scenario of \$20/t CO_2^{-e}, approximately 4 million ha is viable for mixed native species, which will sequester about 66 Mt CO_2^{-e} a year.

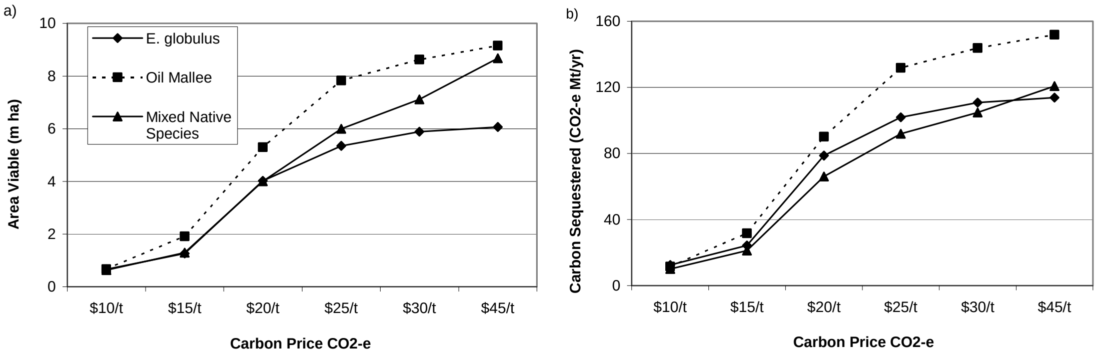

Figure 1: a) Total viable area, and b) total annual carbon sequestered of reforestation under various carbon prices in the cleared agricultural districts, South Australia.

The opportunities and threats presented by widespread reforestation are significant (Table 3). A total of 552,000 ha was identified as high priority for soil and water erosion management and 2.5 million ha as high priority for biodiversity across the study area. For example, at \$20/t CO_2^{-e} over 40% of the area of high priority for managing soil and water erosion could be reforested. On the downside, a significant threat is posed to fresh water yields, with approximately 1,200GL less water available for alternative uses under a \$20/t CO_2^{-e} price scenario (Table 3). An substantial opportunity for biodiversity conservation from reforestation is available if diverse mixes of local native species are used and the benefits could be considerable with widespread high priority areas potentially reforested. Using low diversity species will threaten biodiversity conservation goals across large high priority areas (Table 3). Figure 2 quantifies the difference in annual net economic returns between low and high diversity reforestation in high biodiversity priority locations. The differences are not large (< \$10/ha/yr) for lower carbon prices, but at prices \$25/t and \$45/t, *E. globulus* is on average \$16/ha/yr and \$115/ha/yr more valuable, respectively, in locations of high biodiversity value.

Table 3. Summary of opportunities and threats posed by reforestation under various carbon price scenarios.

		\$10/t	**\$15/t**	**\$20/t**	**\$25/t**	**\$30/t**	**\$45/t**
Opportunity	Proportion of high priority biodiversity areas reforested using mixed native species	6	13	43	59	68	79
	Proportion of high priority soil and water management areas reforested	4	6	41	74	77	78
Threat	Proportion of high priority biodiversity areas reforested using low diversity species	6	14	49	73	79	81
	Increased evapotranspiration from reforestation (GL)	66	197	1178	1504	1534	1550

4. DISCUSSION AND CONCLUSION

This study has identified hotspots of threat and opportunity posed by various permanent reforestation systems to supply carbon permits under the CPRS. Carbon price has a large bearing on the extent of those hotspots. Large parts of the South Australian agricultural landscape are economically viable under higher carbon prices that could realistically be expected once the CPRS is established.

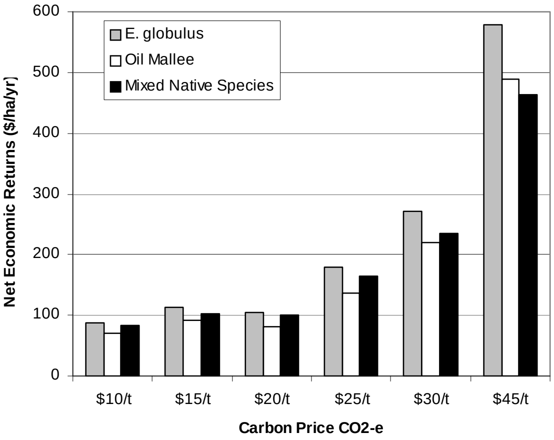

Figure 2. Net economic returns (\$ha/yr) from reforestation in high priority biodiversity conservation locations under various carbon price scenarios.

Various policy options are available to ensure reforestation is steered toward tree species that provide biodiversity benefits (e.g. mixed planting of species with local provenance). For example, a payment for ecosystem services (biodiversity) could be paid to land owners to compensate for the difference in income from the sale of permits generated by high yielding low diversity trees against the lower yielding diverse plantings. This study suggests those subsidies would have to be in the order of only \$5/ha/yr if carbon price is \$20/t of CO_2^{-e}, but up to \$115/ha/yr if carbon price is \$45/t. Regulatory measures could be applied in locations where reforestation threatens water resources. For example, land owners could be required to purchase the water used by the reforested land use, which could be over 1 ML/ha per year in the higher rainfall locations. Water regularly trades at over \$1,000/ML which would have a significant impact on the economic viability of reforestation for carbon permits. No intervention may be the best option where monocultures provide high opportunity and no threat. These are avenues for further research.

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