Assessing South Australian carbon offset supply and policy for co-beneficial offsets: Pollination service supply in lucerne seed production

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Executive summary

This report examines the pollination services delivered to lucerne farming as a co-benefit to revegetation for carbon offset supply. It was carried out as part of the Goyder Institute for Water Research project, *Assessing South Australian carbon offset supply and policy for co-beneficial offsets*. The project seeks to understand the biophysical potential for carbon sequestration across South Australia (SA) as well as the economic constraints to this land use change. Carbon plantings have the potential to provide habitat for wild populations of bees, increasing their presence in the landscape and providing valuable aditional pollination services in the production of pollination dependent agricultural crops.

Lucerne (*Medicago sativa*) is a perennial legume grown extensively in Australia for hay, silage and pasture and seed. Seed production is a very profitable enterprise within lucerne production systems and can be undertaken as the sole focus of the enterprise, as an opportunity crop within hay and grazing production, or within a system that optimises for all three; seed, hay and grazing. Managed and wild pollination services are an important part of the lucerne seed production systems.

In this research we pursued a case study approach to understand the potential co-benefits of pollination services from carbon sequestration through revegetation in South Australia. We developed an idealised hypothetical case study farm to model a range of revegetation scenarios for pollination benefits to understand the economic trade-offs between revegetation and business as usual agriculture. The different revegetation scenarios tested included different spatial extents and configurations of revegetation in the South East of South Australia; and for contexts ranging from low to high habitat suitability for unmanaged pollinators.

To model pollination services for the case study we used the Crop Pollination Model within the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) () model (Sharp *et al.* 2019). This is an index-based model where most parameters are provided as index values between zero and one (0-1). Index values were assigned to parameterise the landscape (land use/land cover) for its ability to provide nesting and foraging habitat for pollinators as well and the different preferences of pollinators and the ability of pollinators to exploit different nesting and foraging habitats. To parameterise the landscape and species index values for land we relied on expert opinion.

To understand the additional income from pollination services that would be required to cover the costs of revegetation across the case study farm we carried out a gap analysis. The gap analysis assessed the costs associated with establishment and maintenance of revegetation and the forgone income from agriculture where revegetation takes place. The gap analysis showed that with a carbon price approaching the current payments in Australia ($10 / tCO_2e$), the cost of revegetation net of payments for sequestered carbon was in the order of 10,000-11,000 per hectare, while at 5 times the current payments net returns would still see producers out of pocket by more than 5000 per hectare.

Results indicate that all habitat suitability scenarios had very low pollinator abundance levels. The relative abundance of pollinators increased more in response to revegetation where habitat suitability was low. i.e. greater relative increases can occur off a low base. This indicates that increasing areal additions of pollinator habitat is most beneficial for crop yield where the initial pollinator abundance is low due to lack of suitable habitat.

The estimated additional economic value of pollination was only a small fraction of this gap under nearly all scenarios considered. Even, under very optimistic assumptions of low habitat suitability (relatively high pollination benefit) and high lucerne seed prices, additional lucerne yield value is estimated at around 40%

of the gap. For most other assumptions, pollination value was estimated to be a much smaller fraction of the net return gap.

The carbon plantings may provide other co-benefits at the same time as the pollination benefits, such as soil conservation, amenity value, water quality improvements, and shelterbelt services. These could conceivably lower the cost of abatement if combined and stacked. However, for this report these benefits were considered singularly in conjunction with carbon benefit. Other co-benefit analyses are presented in Connor *et al.* 2019 and Summers *et al.* 2019.

1 Introduction

1.1 Overview

This report examines the pollination services delivered to lucerne farming as a co-benefit to revegetation for carbon offset supply. It was carried out as part of the Goyder Institute project, *Assessing South Australian carbon offset supply and policy for co-beneficial offsets*. The project seeks to understand the biophysical potential for carbon sequestration across South Australia (SA) as well as the economic constraints to this land use change.

Understanding the potential supply of carbon and which carbon price and policy levers might drive land use change is an important component of climate and economic policy. A recent report examining South Australia's low carbon economy (Hewson *et al.* 2015) identified numerous emissions reduction pathways for SA. These included the potential for improvements in energy efficiency combined with low carbon electricity generation and the electrification of both transport and industry resulting in a halving of overall emissions across SA. The report found that conversion of 37 percent of the eligible land base in the SA would be enough to offset the remaining emissions.

Current economic incentives for carbon sequestration are largely dictated by the Australian Government Emissions Reduction Fund (ERF), which has provided AUD\$2.55 billion over four years for land holders to purchase carbon abatement funding through a reverse auction mechanism. Six ERF auctions have been held since April 2015 with the majority of abatement secured through vegetation practices at an average price of AUD \$12.0 /t CO²e (Evans 2019).

Previous research has found extensive capacity for carbon sequestration through revegetation across SA (Bryan *et al.* 2014). This analysis also found that carbon supply would not be economically viable below \$50 /t CO₂e but would grow rapidly if the price paid for sequestered carbon rose. In other words, for farmers to make money 'growing' carbon they would need to make in excess of \$50 /t CO₂e before they would be better off than if they maintained traditional, business-as-usual agricultural practices. Based on this evidence there is an obvious disparity between the payments available to land holders for carbon abatement activities and the amount required to provide economic incentive to change land use to carbon abatement.

The social, economic and ecological co-benefits of revegetation have long been acknowledged as important components of carbon abatement through revegetation (e.g. Bryan *et al.* 2014; Crossman *et al.* 2011; Paul *et al.* 2013). However, the likely shortfall in income from carbon relative to the combined costs of establishment, maintenance and lost opportunity from agriculture has increased interest in the potential economic co-benefits from revegetation. Consideration of co-benefits may provide sufficient economic incentive to facilitate land use change and encourage carbon sequestration.

This report is one of a series of reports associated with the project including the Technical estimation of carbon supply data and methodology (Settre et al. 2019) and the Carbon supply and cost results reports (Regan et al. 2019).

1.2 Pollination services

Crop pollination is a valuable ecosystem service that is essential for the production of many crops and provides increased yield and quality for other crops (Clarke 2008). Pollination services are valued at

between billions and tens of billions per year globally (Costanza *et al.* 1997; Losey and Vaughan 2006; Southwick and Southwick 1992), with 87 of 115 globally important crops benefiting from animal pollination (Klein *et al.* 2007).

Across Australia, 65% of introduced horticultural and agricultural crops rely on pollination in one form or another to deliver current yields and profitability (Gordon and Davis 2003). The bulk of pollination services across Australia are provided through managed pollinator systems using, primarily, European honey bee (*Apis mellifera*) hives. However, landscapes of mixed agricultural and natural habitats have the potential to provide some pollination service from unmanaged pollinator populations and subsequently produce crops with reduced or completely absent managed hives. This pollination service is associated with habitat conservation and can be a potential co-benefit from revegetation and other conservation efforts.

1.3 Lucerne seed production

Lucerne (*Medicago sativa*) is a perennial legume grown extensively in Australia for hay, silage and pasture. Due to its deep taproot system it is considered somewhat resistant, and resilient, to drought, and well suited to both dryland and irrigated production systems. Vegetative growth extends from a crown at the base of the plant that is capable of repeated growth as long as it remains undamaged.

Lucerne is an excellent source of protein, energy, minerals and vitamins providing very high-quality forage and hay and is also suitable for ensilage. Lucerne provides a number of benefits including lowering the water table, fixing atmospheric nitrogen, increasing soil organic matter and stabilising soil from erosion (Lucerne Australia 2010).

Seed production is a very profitable enterprise within lucerne production systems (RIRDC 2008). Lucerne seed production can be undertaken as the sole focus of the enterprise, as an opportunity crop within hay and grazing production, or within a system that optimises for all three; seed, hay and grazing. Both irrigated and dryland lucerne seed production systems are common in the South East of South Australia, where 85% of the Australian lucerne seed is produced (RIRDC 2008).

Pollination services, typically by European honey bees, are an important part of the lucerne production system (Somerville 2002). While lucerne can self-pollinate, bees aid in 'tripping' the lucerne flowers, an important part of the pollination process that exposes the sexual column. As a result of this, the presence of pollinators results in higher lucerne seed yields and also provides for increased vigour through cross pollination.

In the South East of South Australia, irrigated lucerne seed farmers rely on managed bees to provide pollination services, typically engaging the services of professional apiarists. When required for pollination, hives are dropped in bunches of up to 96 boxes at strategic locations where bees can service large areas, often encompassing multiple irrigated paddocks. A 2014 survey of lucerne seed farmers found that all respondents who produced irrigated lucerne seed brought in managed bees to provide pollination services (Lucerne Australia 2014). Standard fees for pollination services on irrigated lucerne are quite variable ranging between zero and \$50 per hive for the pollination season (approximately 6 weeks). While producers get pollination services from the bees, apiarists also get nectar services from the crops that support honey production and hive health.

In dryland lucerne seed farming systems, producers are much less reliant on managed bees. In the same 2014 survey 11 farmers (~32%) responded that they used managed bees for dryland lucerne

seed production, while 18 farmers (~53%) said they did not use managed bees, and a further two farmers (~6%) explicitly reported that they rely solely on native bees (Lucerne Australia 2014). The other farmers either didn't produce dryland lucerne or could not find an apiarist willing to provide managed hives for dryland systems.

There is a high risk of decline in populations of unmanaged honey bees (*Apis mellifera*) associated with the high risk of the introduction of the Varroa mite (*Varroa destructor*) to Australia (DAWR 2018). One strategy for managing the effects on pollination services if the Varroa mite invades Australia is to manage our remnant vegetation and fortify landscapes through revegetation to protect and increase the numbers of native pollinators (Cunningham *et al.* 2002). The potential for a pollination services as a driver of revegetation adds to the services already driving revegetation, which include carbon sequestration and biodiversity conservation. Put another way, pollination services are a co-benefit of revegetation for carbon sequestration and may influence both the volume and cost of carbon sequestration projects.

1.4 Case study

In this research a case study approach was developed in order to understand the potential co-benefits of pollination services from carbon sequestration through revegetation in South Australia. This was justified on the basis that:

- The use of case studies is a well-established technique in economics (Crosthwaite *et al.* 1997) and landscape analysis (Roxburgh *et al.* 2006, Solecka *et al.* 2019, Summers *et al.* 2015);
- Case studies are suitable because it is impractical to account for or survey all possible variables/populations; and
- The case study approach allows for the addition of other services to bundled co-benefits where markets exist or can be established. e.g. biodiversity, including biodiversity offsets.

1.5 InVEST Crop Pollination Model

The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model (Sharp *et al.* 2019) is a suite of free, open-source models designed to map and value the goods and services that are exploited by humans. Decision makers can quantify trade-offs associated with alternative management choices and identify natural capital investment options and understand the impact on human development and conservation. The InVEST model toolset includes eighteen distinct ecosystem service models for a range of terrestrial, freshwater, marine, and coastal ecosystems.

One of these models in the InVEST suite is the Crop Pollination Model (Sharp *et al.* 2019) which is designed to estimate the ecosystem services provided by unmanaged pollinators. The model seeks to understand how changes in pollinator habitat affects the provision of pollination services for crops. The model is based on the principle that bees require both suitable nesting habitat and floral food resources within foraging distance of nesting habitat. If provided these resources, the pollinators are available to fly from nesting habitat within vegetated areas to nearby crops and pollinate them as they collect nectar and pollen. The model estimates the change in abundance of pollinators that can provide pollinator services to crops based on changes in the surrounding habitat and can also estimate the impact that these changes have on crop yield.

The InVEST Crop Pollination model is an index-based model. As such, most parameters are provided as index values between zero and one (0-1). Index values are assigned to parameterise the landscape (land use/land cover) for its ability to provide nesting and foraging habitat for pollinators as well and the different preferences of pollinators. The ability of bee species to exploit different nesting and foraging habitats is governed by their preferences (e.g. cavity vs ground nesting), seasonal activity (e.g. summer vs winter), foraging distances and relative abundance in the landscape. These index values are assigned for each location and values for multiple species (including for example, European honey bees and native Australian bees) can be assigned. The index values can be assigned based on quantitative field estimates, recorded literature or expert opinion (Sharp *et al.* 2019).

Being an index-based model, outputs should be seen as relative estimates of unmanaged pollinator abundance and pollination of crop yields. Absolute estimates of actual pollinator abundance, nest density and foraging resources and yield impacts are not currently available. Furthermore, pollinator abundance and their impact on crop yield is influenced by landscape stochasticity that is not fully captured in the model. Nonetheless, the index-based model is well suited for making comparison between different scenarios representing changing land management and land cover types.

1.5.1 POLLINATION INPUTS

The InVEST Crop Pollination model requires four main biophysical inputs:

- A land use raster layer;
- An attribute table parameterising the land use classes and their suitability for nesting and foraging index;
- A pollinator guild table that describes how different pollinator species or guilds will interact with the landscape (requires index parameters for pollinator active seasons, nesting preferences, mean flight distances and relative abundances); and
- A shapefile that describes the geospatial location of the farm or paddock of interest, crop type, dependence on pollinators and abundance of managed pollinators (can also be parameterised for on-farm nesting sites and floral resources).

2 Methods

2.1 Study site

More than 85% of the lucerne seed production in Australia is found around Tintinara and Keith in the South East of South Australia (Hogendoorn and Keller 2012). We therefore focused our efforts on this region. We identified an area of 21,000 ha area (15 km by 14 km) to the east of Tintinara and to the North of Keith in which to place the case study (Figure 1). Typical land uses in the areas are:

- dryland grazing;
- irrigated and dryland cereals;
- irrigated and dryland pulses lucerne seed and hay; and
- native vegetation / conservation.

2.2 Case study

We developed an idealised hypothetical case study farm to model scenarios of revegetation for pollination benefits across multiple paddocks and to better understand the economic trade-offs between revegetation and business as usual agriculture. The case study farm was based on typical or average farm properties from the area with the following attributes:

- Total farm size 995 ha;
- Irrigated lucerne centre pivots (162 ha);
- Other cropping (wheat/canola rotation) on rectangular paddocks (154 ha); and
- Dryland grazing mixed pasture (legume/grass mixtures/improved pasture).

The case study farm was geographically located within study site (Figure 1) and used real world land use data to parameterise the model. Thus, the landscape context is typical for dryland lucerne growing conditions in the region.



Figure 1: Study site in the South East of South Australia. The coloured map is centred over coordinates -35.872, 140.162.

2.3 Crop pollination model

As noted above, the crop pollination model requires four main data inputs to estimate unmanaged pollinator abundance in the landscape:

- The Australian Land Use and Management (ALUM) Classification Version 8 was used to provide the land use raster (Figure 1).
- The land use classes were parameterised by experts (Dr Katja Hogendoorn and Dr Scott Groom). These values determine the nesting and foraging preferences of bees in different land use classes (Table 1).
- The pollinator guild table was parameterised by experts (Dr Katja Hogendoorn and Dr Scott Groom) (Table 3).
- The spatial location of the case study farm was developed by visual classification of the study site using Google Earth Pro (Google Inc. 2018). An area determined to be the case study farm was visually classified into the different components of the farm enterprise and shapefiles delineating these areas were created within the Google Earth Pro using the Add Polygon feature (Figure 2). The parameterisation of key variables that determine pollination for the crops within the farm (i.e. lucerne and canola pollination and flowering properties) were developed from the literature and through consultation with experts (Dr Katja Hogendoorn and Dr Scott Groom).



Figure 2: Idealised hypothetical case study farm with the different revegetation scenarios. For the purposes of modelling the circular paddocks were parametrised as lucerne and the rectangular paddocks were parametrised as other crops.

2.3.1 REVEGETATION SCENARIOS

Revegetation scenarios were examined by altering the land use raster layer that details the background pollinator nesting and foraging information for the model (see below).

Revegetation patches were attributed the same nesting and foraging parameters as the highest value remnant vegetation within the landscape. This was the land use class 'Conserved area' (see Table 1 for parameters).

Whole of farm case study

For the whole farm case study, we selected areas around the hypothetical farm where revegetation was to be established – revegetation areas. These were areas as close as possible to the largest lucerne paddocks on the farm (approximately 40 ha of lucerne each), and were restricted to current grazing land use areas – that is to say revegetation was not placed in areas classified as cropping or lucerne

paddocks. We created a number of revegetation scenarios with increasing area of revegetation. The scenarios examined were vegetation patches of 2 ha, 4 ha, 8 ha, 32 ha, 40 ha and 80 ha.

Single paddock case study

There are many possible configurations of revegetation around any given farm. In the whole farm case study presented here we optimised revegetation for proximity to the largest area of lucerne paddocks given the existing layout in order to maximise the proximity of pollinator nesting habitat to the largest area of crop. Different native vegetation planting configurations were developed around a single paddock scenario to determine the impact of the size and distance of vegetation patches from target paddocks on pollination services. For the single paddock case study, the 'target paddock' had an area of 43 ha.

The 'donut' revegetation pattern examined revegetation patches that surround the target paddock completely forming the shape of a donut. Given that many of the paddocks in the area are circular based on centre pivots we considered this a plausible design. The scenarios for the donut revegetation pattern included total revegetated areas of 2 ha, 4 ha, 16 ha, 20 ha, 30 ha and 40 ha (Figure 2). This scenario represents the best-case scenario for revegetation pattern for pollination benefits with the expectation that it would create the highest level of increased pollination services.

The hedgerows revegetation scenario examined an alternative revegetation strategy where strips of vegetation simulate hedgerows that might be found around paddocks. We anticipated that replanting extensive contiguous areas with revegetation will have the highest pollination benefit but will also remove large areas of farm from business as usual agricultural production. Alternatively, hedgerows planted around the farm could perhaps be more easily integrated into current production systems exploiting road and paddock edges or areas of low agricultural productivity. They may also provide other benefits. e.g. shelter belts for grazing livestock. However, due to the larger distances from the crops we anticipated that this scenario would not provide the highest pollination benefit.

The hedgerows revegetation pattern examined the addition of 8 ha revegetation patches at increasing distances from the target paddock (Figure 3).



Figure 3: Single paddock revegetation scenarios showing the area of revegetation for each scenario in hectares and as a percentage of the area of the circular paddock.

2.3.2 LAND USE HABITAT SUITABILITY SCENARIOS

The pollinator habitat suitability parameterisation of the different land use classes (Table 1) was carried out through consultation with experts. However, because of the large amount of variability in ALUM land use classes it was decided to examine scenarios of different land use habitat suitability classes.

Specific classes that were thought to have variability in habitat suitability not captured in the land use classification were: Grazing modified pastures, Pasture legumes, Pasture legume/grass mixtures, Cropping, Cereals and Pulses. These classes occupy a large area of the study site (Table 1) and/or are thought to be subject to significant variability in their habitat suitability for nesting and foraging. For example, a grazing paddock will have significantly better habitat if it contains a lot of old standing trees that provide nesting habitat compared with one that has very few trees. Similarly, vegetation on the side of paddocks could provide foraging resources if suitable plants are present. In order to examine potential variability in these classes a number of nesting and floral resource suitability scenarios were examined. These habitat suitability scenarios were a Low Habitat Suitability, a Medium Habitat Suitability and a High Habitat Suitability (Table 1).

2.3.3 FARM POLLINATOR ABUNDANCE AND CROP YIELD ESTIMATES

The model also estimates the contribution of unmanaged pollinators to total crop yield. The model calculates an index of total yield and the contribution of unmanaged pollinators to that yield.

In the model runs here we looked at dryland and irrigated lucerne seed production. Based on the literature and the 2014 Lucerne Growers Survey (Lucerne Australia 2014), we estimated that dryland lucerne required one quarter the abundance of pollinators needed for irrigated lucerne.

	Lov	v habitat suit	ability	Mediu	um habitat sui	itability	Hig	h habitat suit	ability	Area	a
	Cavity	Ground	Floral	Cavity	Ground	Floral	Cavity	Ground	Floral	Hostoros*	% study
Land use	nesting	nesting	resources	nesting	nesting	resources	nesting	nesting	resources	nectares	area
Conserved area	0.8	0.7	0.4	0.8	0.7	0.4	0.8	0.7	0.4	180.7	0.86
Residual native cover	0.7	0.5	0.3	0.7	0.5	0.3	0.7	0.5	0.3	972.2	4.63
Rehabilitation	0.6	0.5	0.3	0.6	0.5	0.3	0.6	0.5	0.3	4.3	0.02
Grazing native vegetation	0.7	0.1	0.2	0.7	0.1	0.2	0.7	0.1	0.2	163.5	0.78
Plantation forests	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6	25.7	0.12
Environmental forest plantation	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4	0.2	9.8	0.05
Grazing modified pastures	0.0	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	2927.2	13.94
Pasture legumes	0.0	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	727.4	3.46
Pasture legume/grass mixtures	0.0	0.1	0.3	0.2	0.1	0.3	0.3	0.1	0.3	11839.7	56.38
Cropping	0.0	0.3	0.0	0.1	0.3	0.0	0.1	0.3	0.0	1320.6	6.29
Cereals	0.0	0.3	0.0	0.1	0.3	0.0	0.1	0.3	0.0	127.0	0.60
Pulses	0.0	0.3	0.0	0.1	0.3	0.0	0.1	0.3	0.0	45.0	0.21
Grazing irrigated modified pastures	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	139.7	0.67
Irrigated pasture legumes	0.0	0.1	0.3	0.0	0.1	0.3	0.1	0.1	0.3	864.8	4.12
Irrigated legume/grass mixtures	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.2	155.9	0.74
Irrigated cropping	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	717.3	3.42
Irrigated cereals	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	57.8	0.28
Irrigated grapes	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	1.5	0.01
Abandoned irrigated land	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	131.5	0.63
Dairy sheds and yards	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.05
Residential and farm infrastructure	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	8.3	0.04
Rural residential with agriculture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	6.6	0.03
Farm buildings/infrastructure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.1	0.42
Recreation and culture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	31.4	0.15
Airports/aerodromes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.5	0.12
Roads	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	349.4	1.66
Railways	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.2	0.32
Quarries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.01

Table 1: Land use classifications within the study area and the different nesting and floral attributes under the three different habitat suitability background scenarios.

* Total area (ha) of land use classes within the study area

2.4 Economic analysis

An economic gap analysis was carried out to determine the necessary additional income from pollination services that would be required to cover the costs of revegetation across the hypothetical farm. The gap analysis looked at all the costs associated with establishment and maintenance of revegetation and the forgone income from agriculture where revegetation takes place. All data used in the economic analysis was taken from Regan *et al.* (2019).

The net present value (NPV) was calculated with three potential planting methods (direct seeding, mechanical tubestock planting and manual tubestock planting; Table 2), which were depreciated over 100 years at a 5% discount rate. Maintenance costs were also included (Table 2) but are only considered for the first 10 years. The NPV was then calculated over 100 years at a range of carbon prices (Table 3). The NPV indicates how much money would be lost or made from sequestered carbon at the different carbon prices over the 100 years. Finally, the gap analysis (Table 4) indicates the additional per hectare income required to overcome the change from business as usual agriculture to revegetation.

Table 2: Costs for the different establishment methods with maintenance costs (Regan et al. 2019).

Planting Method	(\$/ha)
Direct seeding	2,008
Mechanical tubestock	2,726
Manual tubestock	2,843
Maintenance costs (10 years)	5,750

Table 3: NPV over 100 years taking into account establishment costs, maintenance costs and opportunity costs. These figures indicate how much revenue (\$/ha) will be lost or gained from carbon alone over 100 years under the different establishment options (Regan *et al.* 2019).

Carbon price (\$/t CO ₂ e)	Direct seeding (\$/ha)	Mechanical tubestock (\$/ha)	Manual tubestock (\$/ha)
10	-10,116.80	-10,834.80	-10,951.8
25	-8,403.91	-9,121.91	-9,238.91
50	-5,549.03	-6,267.03	-6,384.03
75	-2,694.16	-3,412.16	-3,529.16
100	160.72	-557.284	-674.284

3 Results

3.2 Revegetation scenarios

Revegetation scenarios were examined looking at a whole of farm case study and an individual paddock case study.

3.2.1 WHOLE OF FARM CASE STUDY

Pollinator abundance

The whole of farm case study examined changes in pollinator abundance across multiple paddocks. Figure 4 shows the pollinator abundance index and percentage change in the pollinator abundance index for increasing areas of revegetation, as well as the estimated contribution of unmanaged pollinators to crop yield in irrigated and dryland production systems. A summary of the findings is described below:

- Pollinator abundance increased linearly with additional revegetation. However, overall abundance indices were low. In the low habitat suitability scenario, the abundance index changed from 0.026 with no additional revegetation on the farm property to 0.031 with an additional 40 ha. In the medium habitat suitability scenario, the abundance index changed from 0.086 with no additional revegetation on the farm property to 0.089 with an additional 40 ha. In the high habitat suitability scenario, the abundance index changed from 0.117 with no additional revegetation on the farm property to 0.12 with an additional 40 ha.
- The difference between the different habitat suitability scenarios was much more significant than the differences between revegetation scenarios. The habitat suitability scenarios are where the background land use classes were given different habitat suitability indexes (Table 1), whereas the revegetation scenarios were where additional revegetation was added around the farm. With no added revegetation the high habitat suitability scenario had a pollinator abundance index of 0.117 compared with 0.026 in the low habitat suitability and 0.086 for the medium habitat suitability scenario.
- Despite overall low values in pollinator abundance, for some scenarios the relative increase in
 pollinator abundance was quite large. For example, in the low habitat suitability model, pollinator
 abundance increased by 20 % with the additional 40 ha. However, for medium and high habitat
 suitability models, relative increases in pollinator abundance with increasing revegetation was
 considerably lower, 3.8% for the medium habitat suitability model and 1.9% for high habitat
 suitability model.
- The irrigated crop scenario showed small changes in crop yield from increased vegetation consistent with the low increase in pollinator abundance. This is consistent with the low estimated abundance of pollinators and the expected level of pollinators required to deliver a profitable crop. As with pollinator abundance, relative increases in crop yield were varied ranging from 16% for the low habitat suitability scenario to 2.2% for the medium scenario and 0.95% for the high habitat suitability.



Figure 4: Change in the abundance index of pollinators and percent change in pollinator abundance with increasing revegetation for the farm case study. High, medium and low refer to the habitat suitability scenarios examined in the different analyses.

3.2.2 SINGLE PADDOCK SCENARIO

The single paddock scenarios examined revegetation around an individual paddock making it possible to examine the different plantation strategies. Despite optimising the revegetation patterns around the single paddock the pollinator abundance was very similar to the whole farm.

As with the whole of farm scenario there were very low pollinator abundance levels across the different habitat suitability scenarios. Similarly, there was a much greater response to increased revegetation area in the low habitat suitability scenario compared to the medium and high habitat suitability scenarios.

The donut revegetation strategy (Figure 5) saw pollinator abundance increase from:

- 0.023 to 0.03 for the low habitat suitability scenario;
- 0.092 to 0.096 for the medium habitat suitability scenario; and
- 0.12 to 0.13 for the high habitat suitability scenario with 40 additional hectares of revegetation.

The hedgerow revegetation strategy (Figure 6) saw pollinator abundance increase from:

- 0.023 to 0.028 at 40 ha for the low habitat suitability scenario;
- 0.092 to 0.095 at 40 ha for the medium habitat suitability scenario; and
- 0.128 to 0.13 at 40 ha for the high habitat suitability scenario.

As with the whole farm scenario, despite small changes in the absolute abundance of pollinators there were larger percentage increases in pollinator abundance for both the donut and hedgerow scenarios, particularly for the low habitat scenario. For both the donut and the hedgerow scenarios the dryland crop yield index saw a larger absolute increase compared with the irrigated crop yield index although a lower percentage increase.



Figure 5: Donut revegetation strategy results for low, medium and high habitat suitability scenarios: pollinator abundance, irrigated crop yields, and dryland crop yields.



Figure 6: Hedgerows revegetation strategy results for low, medium and high habitat suitability scenarios: pollinator abundance, irrigated crop yields, and dryland crop yields.

3.3 Economic analysis

The economic analysis considering only carbon benefits but not pollination benefits and all relevant costs (of establishing and maintaining new plantings, and lost grazing production value) indicate that at most carbon prices, the costs of planting and maintaining carbon, and the lost opportunity from agriculture, would not be sufficient to achieve positive NPV. The only carbon price scenario that achieves a positive NPV over 100 years from carbon plantings alone is \$100 /t CO₂e with direct seeding (the lowest cost planting method) (Table 4). All other cost and planting scenarios have negative NPV.

Table 4: Gap analysis performed on the results of the NPV values in Table 3. The figures here represent the increased net revenue that would be needed from dryland lucerne seed production to offset the costs of establishment, including opportunity costs from forgone agriculture, for the revegetation project. These figures are calculated assuming a 100 year payback timeline (Regan *et al.* 2019).

Carbon price (\$/t CO2e)	Direct seeding (\$/ha)	Mechanical tubestock (\$/ha)	Manual tubestock (\$/ha)
10	509.72	545.89	551.79
25	423.42	459.59	465.49
50	279.58	315.75	321.65
75	135.74	171.92	177.81
100	Positive NPV	28.08	33.97

This means that for economic viability of plantings, economic value from pollination services, or other cobenefits need to make up the difference between returns to carbon payments net of all costs. For example, at carbon price of $10/t CO_2$ additional economic co-benefits worth around 510/ha/year would be required for the plantings to be a breakeven proposition.

To understand this gap between likely economic return and additional benefit from pollination required for economic viability, potential additional return from estimated additional pollination was computed. We considered the 40 hectare (most pollination benefit) and donut (best case configuration) case. Given, uncertain and variable yield, a range of typical yield and lucerne price values were considered. Historical yield data (Table 5) for dryland lucerne production in the Tintinara area was sourced from Seed Services Australia (SSA), a seed certification and consultation business within Primary Industries and Resources SA (PIRSA).

Table 5: Annual average lucerne seed yields for South East of South Australia 2009-2018.

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Yield (kg/ha)	316	248	74	201	200	245	81	214	215	251

The average yield over the 10 year period 2009-2018 was 204.5 kg/ha.

Given results from the pollination impact modelling for the 40 ha hedgerow scenario, Table 6 summarises the yield increases (kg/ha of 10 year average yield) that could be expected under the varying habitat suitability scenarios ().

Table 6: Estimated potential yield benefit from pollination as a result of 40 hectare hedgerow revegetation for a casestudy 40 hectare dryland lucerne seed paddock in the South East of South Australia.

	Habitat suitability						
	low	med	high				
Yield increase (% of current yields)	16	2.2	0.95				
New yield (kg/ha)	237.22	209.00	206.55				
Δyield (kg/ha)	32.72	4.50	1.94				

Indications from SSA are that lucerne seed prices are highly volatile from year to year and are particularly dependant on international export markets such as Saudi Arabia and the certification status of the seed (Koch, N, *pers. comm.* May 2017). As such applying an average price in the economic analysis is fraught. This was addressed by calculating the profitability benefits from revegetation using a range of potential farm gate price of \$2/kg - \$10/kg. The \$8/kg - \$10/kg are likely to be optimistic estimates of lucerne seed price.

The following table (Table 7) outlines the calculated estimates of revenue increases (\$/ha/yr) as a result of increase in pollination services for the 3 habitat suitability scenarios and for a range of lucerne seed prices.

Habitat				e (\$/kg)					
suitability	2	3	4	5	6	7	8	9	10
Low	\$65.44	\$98.16	\$130.88	\$163.60	\$196.32	\$229.04	\$261.76	\$294.48	\$327.20
Med	\$9.00	\$13.50	\$18.00	\$22.50	\$26.99	\$31.49	\$35.99	\$40.49	\$44.99
High	\$3.89	\$5.83	\$7.77	\$9.71	\$11.66	\$13.60	\$15.54	\$17.48	\$19.43

Table 7: Estimated improvement in economic return (\$/ha/yr) to lucerne seed production from improved pollination

The results (Table 7) show that at carbon prices in the range near to the recent ERF auctions round prices (\$10 /t CO²e) and assuming lucerne prices in the middle of the range considered, the estimated economic value of pollination (\$196/ha/year) are only about 40% of the co-benefit income required for the plantings to represent a breakeven proposition for the low habitat suitability case. For medium and high habitat suitability locations the economics are much more limiting, with economic value for pollination benefit representing around 5% and 1% of the gap between costs and returns for these cases. Economics are naturally more favourable under assumption of higher lucerne prices. Still, we find few if any plausible assumptions lead to a conclusion that carbon plus pollination co-benefits would create sufficient economic value to justify related costs.

4 Discussion and conclusions

We have examined a range of revegetation scenarios at farm and paddock scale to assess the potential for economic returns from carbon sequestration where a pollination co-benefit to agriculture can be simultaneously produced. The different revegetation scenarios tested included different spatial extent and configuration of revegetation in different landscape contexts in the lucerne growing area of the South East of South Australia; and for contexts ranging from low to high habitat suitability for unmanaged pollinators.

All habitat suitability scenarios indicated very low pollinator abundance levels. The relative abundance of pollinators increased more in response to revegetation where habitat suitability was low. i.e. greater relative increases can occur off a low base. This indicates that increasing areal additions of pollinator habitat is most beneficial for crop yield where the initial pollinator abundance was low due to lack of suitable habitat.

The results also show that with a carbon price of $10 / t CO^2$ (near the price in the latest ERF auction) the net cost for converting existing farmland to revegetation when accounting for payments for sequestered carbon is in the order of 10,000 - 10,000 / ha (depending on revegetation method). The net return is still estimated to be negative (greater than 5,000 / ha net cost) when payments for carbon are five times as great ($50 / t CO^2e$).

The estimated additional economic value of pollination is only a small fraction of this gap under nearly all scenarios considered. Even, under very optimistic assumptions of low habitat suitability (relatively high pollination benefit) and high lucerne seed prices, additional lucerne yield value is estimated at around 40% of the gap. For most other assumptions, pollination value is estimated to be a much small fraction of the net return gap. Consequently, the results do not provide much support for the idea that crop yields increases from improved unmanaged pollination plus value of carbon credit associated with revegetation together would represent sufficient joint benefit value to stimulate significant changes in land use. At least not at current carbon and lucerne seed prices. However, higher lucerne seed and/or carbon prices may change the incentive to revegetate. Such a scenario can be imagined where unmanaged pollination services can supplied from revegetation and managed hive prices increase as a consequence of the arrival and spread of Varroa mite (Cook *et al.* 2007).

Pollination is only one of the potential services produced as a co-benefit with carbon sequestration with revegetation, and the present study may undervalue total benefits by not considering other services. Primary amongst other services enhanced is that of biodiversity conservation. Biodiversity conservation in Southern Australia is particularly impacted by fragmentation from past clearance for agriculture. The effects of fragmentation include loss of sufficient total habitat for some species, reductions in quality of habitat and increases in pest and weed invasion from edge effects. The mosaic of agricultural land and native vegetation in rural landscapes in Southern Australia is frequently sub-optimal for biodiversity conservation (e.g. Radford *et al.* 2005). Revegetation efforts in highly cleared landscapes can produce biodiversity conservation services if they are appropriately designed and managed (Bennett *et al.* 2006). However, markets for biodiversity services are only just beginning to emerge and trade-offs between co-benefits bundled in revegetation need to be considered.

References

- Bennett, A., Radford, J. and Haslem, A. (2006) *Properties of Land Mosaics: Implications for Nature Conservation in Agricultural Environments.*
- Bryan, B.A., Nolan, M., Harwood, T.D., Connor, J.D., Navarro-Garcia, J., King, D., Summers, D.M., Newth, D., Cai, Y., Grigg, N., Harman, I., Crossman, N.D., Grundy, M.J., Finnigan, J.J., Ferrier, S., Williams, K.J., Wilson, K.A., Law, E.A. and Hatfield-Dodds, S. (2014) Supply of carbon sequestration and biodiversity services from Australia's agricultural land under global change. *Global Environmental Change* 28(0), 166-181.
- Clarke, M. (2008) *Pollination Australia: Research and Development Priorities*, Rural Industries Research and Development Corporation, Canberra, Australia.
- Connor, J., Summers, D., Regan, C., Abbott, H., Frizenschaf, J. and van der Linden, L. (2019) *The economics of riparian plantings for carbon and water quality benefits in the Mount Lofty Ranges*, Goyder Institute for Water Research Technical Report Series No. 19/06, Adelaide, Australia.
- Cook, D.C., Thomas, M.B., Cunningham, S.A., Anderson, D.L. and De Barro, P.J. (2007) Predicting the economic impact of an invasive species on an ecosystem service. *Ecological Applications* 17(6), 1832-1840.
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Niell,
 R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253-260.
- Crossman, N.D., Bryan, B. and Summers, D.M. (2011) Carbon payments and low-cost conservation. *Conservation Biology* 25(4), 835-845.
- Crosthwaite, J., MacLeod, N.D. and Malcolm, B. (1997) *Case Studies: Theory and Practice in Agricultural Economics*, Gold Coast, Australia.
- Cunningham, S., FitzGibbon, F. and Heard, T. (2002) The future of pollinators for Australian agriculture.
- DAWR, A.G.D.o.A.a.W.R. (2018) Bees and Bee Pests and Diseases, Available at <u>http://www.agriculture.gov.au/pests-diseases-weeds/bees</u>, Accessed on 22 June 2018.
- Evans, M.C. (2018) Effective incentives for reforestation: lessons from Australia's carbon farming policies. *Current Opinion In Environmental Sustainability* 32, 38-45.
- Google Inc. (2018) Google Earth Pro V7.3.1.4507, Image date: 16th November 2016, longitude: 140.165 latitude: -35.868, Available, Accessed on 15 February 2018.
- Gordon, J. and Davis, L. (2003) *Valuing honeybee pollination*, Rural Industries Research and Development Corporation.
- Hewson, J., Skarbek, A. and Jotzo, F. (2015) *South Australia's low carbon economy experts panel: Findings and recommendations*, South Australian Government.
- Hogendoorn, K. and Keller, M. (2012) *Native Australian Bees as Potential Pollinators of Lucerne*, Rural Industries Research and Development Corporation, Canberra, Australia.
- Klein, A.-M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. and Tscharntke,
 T. (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal* Society B: Biological Sciences 274(1608), 303-313.

- Losey, J.E. and Vaughan, M. (2006) The Economic Value of Ecological Services Provided by Insects. *Bioscience* 56(4), 311-323.
- Lucerne Australia (2010) General information about lucerne, Available at http://www.lucerneaustralia.org.au/pages/lucerne-info/general-information-about-lucerne.php, Accessed on 15 March 2018.
- Lucerne Australia (2014) Lucerne Australia 2014 Pollination Survey, Lucerne Australia Kieth, South Australia.
- Paul, K.I., Reeson, A., Polglase, P., Crossman, N., Freudenberger, D. and Hawkins, C. (2013) Economic and employment implications of a carbon market for integrated farm forestry and biodiverse environmental plantings. *Land Use Policy* 30(1), 496-506.
- Radford, J., Bennett, A. and J. Cheers, G. (2005) Landscape-level thresholds of habitat cover for woodlanddependent birds.
- Regan, C., Connor, J., Settre, C., Summers, D.M. and Cavagnaro, T. (2019) Assessing South Australian Carbon Offset Supply and Cost, Goyder Institute for Water Research Technical Report Series No. 19/05, Adelaide, Australia.
- RIRDC, Rural Industries Research and Development Corporation (2008) *Economic Analysis of the Australian Lucerne Seed Industry*.
- Roxburgh, S.H., Wood, S.W., Mackey, B.G., Woldendorp, G. and Gibbons, P. (2006) Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia. *Journal Of Applied Ecology* 43(6), 1149-1159.
- Settre, C., Regan, C. and Cavagnaro, T. (2019) *Technical estimation of carbon supply data and methodology report*, Goyder Institute for Water Research Technical Report Series No. 19/04, Adelaide, Australia.
- Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D. and Douglass, J. (2018) InVEST 3.4.4 User's Guide. *The Natural Capital Project*, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
- Solecka, I., Raszka, B. and Krajewski, P. (2018) Landscape analysis for sustainable land use policy: A case study in the municipality of Popielów, Poland. *Land Use Policy* 75, 116-126.
- Somerville, D. (2002) Lucerne pollination, Agnote DAI-134, NSW Agriculture.
- Southwick, E.E. and Southwick, J.L. (1992) Estimating the Economic Value of Honey Bees (Hymenoptera: Apidae) as Agricultural Pollinators in the United States. *Journal Of Economic Entomology* 85(3), 621-633.
- Summers, D.M., Bryan, B.A., Meyer, W.S., Lyle, G., Wells, S., McLean, J., Moon, T., van Gaans, G. and Siebentritt, M. (2015) Simple models for managing complex social–ecological systems: The Landscape Futures Analysis Tool (LFAT). *Environmental Modelling & Software* 63(0), 217-229.
- Summers, D.M., Regan, C., Connor, J. and Cavagnaro, T. (2019) *Assessing South Australian carbon offset supply and policy for co-beneficial offsets: shelter belts for lamb mortality reduction*. The Goyder Institute for Water Research Technical Report Series No. 19/08, Adelaide, South Australia.





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