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Agroforestry: realising the triple bottom line benefits of trees in the landscape

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June 2018

[Insert ISBN or ISSN and cataloguing-in-publication (CiP) information if required]

Citation

O'Grady AP, Mitchell PJ (2017) Agroforestry: realising the triple bottom benefits of trees in the landscape. CSIRO, Australia.

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Acknowledgments

This work was funded through the Australian Government's Rural Research and Development for Profit grant entitled '*Lifting farm gate profit through high value modular agroforestry*'. We acknowledge the support of our partner organisations, Forest and Wood Products Australia, Dairy Australia, Forico and Greening Australia.

Executive summary

Agroforestry is often seen as being a key farming systems option to improve future landscape management and agricultural intensification. Australia has had a long history of agroforestry and a considerable research effort was conducted prior to and during the Joint Venture Agroforestry Project to assess the potential economic, environmental and social outcomes associated with agroforestry. Powell, (2009) published an excellent synthesis of the 15 year program. The program was seeded by two main objectives; in higher rainfall areas, the main objective was to augment wood supplies from public native forests and in medium to lower rainfall sites to address environmental issues and land degradation such as salinity.

Moving forward these objectives remain relevant today. Additionally, there is rising global demand for wood products to both mitigate and adapt to rapidly changing climates as a substitute for carbon and steel. These are mega-trends with potentially significant opportunities for the Australian forestry sector. Historical practices of clearing native forests to make way for plantations are generally no longer politically acceptable, thus agroforestry represents a pathway to augmenting demand for wood in these areas. Similarly in mid to lower rainfall areas much of the agroforestry is geared towards environmental benefits that can flow from integrating trees into agricultural landscapes, in particular the sequestration of carbon in trees, enhancing the biodiversity of agricultural landscapes and management of dryland problems such as salinity. There remains a focus on potential payments for environmental services to incentivise farmers.

Despite the promise of agroforestry, there has been a perception that it may not have lived up to its potential- either because the benefits to farm profitability have not been realised or farmers may not understand the full suite of benefits that flow from agroforestry or how these help the enterprise profitability. Since the end of the JVAP program there has been little research focus on agroforestry. Funding as part of the Rural Research for Profit Programme of the Department of Agriculture and Water Resources has enabled CSIRO and FWPA to take another look at agroforestry in Australia today. The review explores agroforestry options for southern Australia with a particular emphasis on examining the benefits to farmers. It takes an evidence based approach to explore the economic and biophysical basis for a range of benefits. It examines the evidence for direct and indirect commercial benefits, the flow of environmental services that arise from agroforestry and then explores existing tools that provide an integrated overview of agroforestry at the farm scale.

Trees can deliver a broad range of commercial products to supplement farm incomes, including pulp and solid wood products and a range of potentially emerging markets including carbon, biofuels and oils. Powell, (2009) concluded that in higher rainfall areas commercially focused agroforestry was marginally profitable, largely due to the long return times associated with agroforestry (20-30 years) and in lower rainfall areas probably unprofitable. A review of the economic studies associated with agroforestry in southern Australia highlights that under most circumstances the net present value was positive. Agroforestry based on common commercial species was typically profitable at discount rates below eight percent, and in some cases at discount rates considerably higher. However, in many of these case studies the analysis only

considered the direct commercial benefits associated with timber production. Few studies have examined the opportunity costs through a formalised benefit cost analysis and very few considered indirect commercial benefits associated with agroforestry. Trees on farms have a number of indirect commercial benefits that remain poorly quantified. Trees have been shown to provide shelter for pasture and livestock, ameliorating stress associated with heat and cold. This can result in increased yields, reduced mortality of young livestock and improved animal welfare. While there is a general recognition that these are benefits associated with agroforestry, the quantitative evidence remains sparse on the ground. As a result many of these interactions are not included in financial analysis of the agroforestry venture and as a result formalised valuation techniques may underestimate the benefits.

Carbon markets and biomass for energy have long been viewed as pathways to increase the profitability of agroforestry and as a way of incentivising farmers particularly in lower rainfall environments. However, there remains uncertainty of the potential for these to fill this role, at both a policy and at an enterprise level. The Carbon Farming Initiative methodology for farm forestry recognises that agroforestry can play a role to significantly increase the storage of carbon in agricultural landscapes. Similarly, the potential for use of biomass as a feedstock for alternative energies and biofuels remains high but to date are unrealised. There is an extensive body of work that addresses the opportunities for biomass in the energy space in Australia. No doubt this will continue to provide considerable potential. However, agroforestry specifically based on providing a feedstock for bioenergy may have to compete with a vast amount of residue material arising from commercial forestry and agricultural enterprises.

Agroforestry can deliver significant environmental dividends for society as a whole. These externalities have been long recognised and are the drivers for much interest in payments for environmental services. The environmental benefits of trees are realised in many different types of forestry systems from industrial plantations through to ecological restoration. Management of excess recharge and discharge sites (including salt land) has relied on targeted species-site selection and its efficacy has ultimately been dependent on underlying catchment hydrogeology. Agroforestry offers significant benefits for the retention and management of soil and excess nutrients, particularly in riparian areas and drainage channels. Information on the design and management of tree belts to achieve these objectives are reasonably well defined. The extent to which agroforestry fosters biodiversity and native habitat depends on the system and its ecological setting, such as the proximity to native remnant vegetation, the size and shape of the tree stands and the species composition and size/age structure. In general, agroforestry is likely to provide additional habitat for many species compared to adjacent agricultural landscapes. The potential for biodiversity enhancement from farm forestry can be assessed qualitatively using: site-level factors - characterised by complexity, composition and ecological management, and landscape-level factors - characterised by location and configuration. In the absence of overarching frameworks that capture the full suite of these benefits, the quantification of the cumulative impact of agroforestry on environmental health is best done for a particular outcome or provisioning service e.g. nutrient and sediment management.

In recent years there has been increasing concern in relation to declines in native and introduced pollinators. Emerging international evidence suggests that agroforestry has an important role to

play in the ecological intensification of highly modified agricultural landscapes. Even simple agroforestry systems in these landscapes can have a significant impact on the abundance and diversity of pollinators. In Australia, very little has been done to improve our understanding of the role of native pollinators in agricultural production. This is however changing, driven by concerns that the domestic honeybee industry faces significant biosecurity threats and the pollination industry faces the dual challenges of rapidly expanding horticultural production and increasing competition with honey production.

A major assumption underlying the limited uptake of agroforestry in Australia is that the benefits of agroforestry adoption for farmers are limited. A major barrier to this is a lack of suitable tools for identifying and quantifying these benefits. Even indirect commercial benefits, e.g. increased yields or decreased mortality, remain hard to quantify. Furthermore, a focus of the agroforestry literature in relation to the environmental services that agroforestry may deliver has been to focus on these as externalities, i.e. the benefits flow to the broader society, but with limited benefit and a potential opportunity cost to the landowner. Very few studies have questioned this assumption, and most studies make an implicit assumption that that the farm enterprise is inextricably dependent on the inputs of these environmental services (as opposed to famers as suppliers of environmental services). Natural capital accounting is being proposed as a potential mechanism for internalising these externalities. While, the idea of natural capital accounting, and the associated valuation of environmental services is not new, application of these principals at the scale of a farm enterprise is. Furthermore, financial institutions and downstream customers are increasingly aware of the “sustainability risk” within their supply chains. Integrated reporting of the financial and natural capital within the farm balance sheet offers a potential pathway to demonstrate the benefits of agroforestry in a way that has not been previously considered, though this thinking remains in its infancy.

1 Introduction

Agroforestry refers to a set of farming practices that have been practised for millennia (Nair, 1993). While there has been considerable debate over the definition of agroforestry, Nair (1993) provides an excellent summary of the history and definitions of agroforestry. Briefly, the features of agroforestry defined by Nair (1993) were that agroforestry is the deliberate growing of woody perennials on the same land as either agricultural crops or animals, to deliver significant ecological or economic interactions (positive or negative) between the plant or animal production system.

Despite the relative simplicity of this statement, agroforestry is complex, as the motivations and drivers for incorporating agroforestry into farming systems are as diverse as the individual farming enterprises themselves. This diversity of motivations and drivers has attracted considerable research over a number of years, however a common characteristic of this research is a desire to assess and quantify the multiple benefits associated with agroforestry. These benefits include; sustaining rural livelihoods, promotion of productive and resilient agricultural environments and when practiced at scale, enhancement of carbon storage, reduced deforestation, protection of soil and water resources and provision of habitat to promote biodiversity (Buttoud et al., 2013). An overarching challenge associated with these objectives has always been the quantification of these benefits and the capacity to explicitly articulate the benefits that flow to the farm enterprise (Ogilvy, 2015). As a result there is ongoing interest in the application and adoption of agroforestry.

Agroforestry has come to be seen as an integral part of intensifying agricultural landscapes. This is driven by a number of factors ranging from global megatrends (sensu Hajkowicz and Moody (2010) such as: a need to increase resource use efficiency and getting more from less through to a desire to increase farm amenity (Fenton, 2010) and, a requirement to make agriculture more resilient to future climatic variability (Kaczan et al., 2013). The potential for agroforestry to drive sustainable development globally has also been recognised in international policy meetings such as the United Nations Framework Convention on Climate Change (UNFCCC, 2006) and the Convention on Biological Diversity (https://www.cbd.int/convention/, viewed 8/5/2017). Despite this recognition, agroforestry continues to face challenges such as unfavourable policy settings, inadequate knowledge dissemination, legal constraints and poor co-ordination among the multiple sectors. In industrialised nations an emphasis on monoculture production systems, industrial agriculture and increasing mechanisation may lead to a perception that trees are incompatible with farm operations, and that agroforestry is more suited to low output subsistence systems (Buttoud et al., 2013). However, increasingly farmers are being recognised as stewards of large tracts of land and that the economic and environmental services that this resource provides, has benefits that extend beyond the farm gate. Thus, there is emerging recognition that society may have an obligation to share the cost of managing this resource (Wentworth Group, 2008). Markets for environmental services provide potential to subsidise the high costs and perceived low profitability associated with tree planting on farms, although to date development and uptake has been slow.

The world’s population is predicted to be approximately 9.7 billion by 2050 (source http://www.un.org/en/development/desa/news/population/2015-report.html, viewed

20/2/2017). This continued population growth is a major determinant of future food and fibre demands. As such, it is anticipated that there will be strong demand for wood products into the future, driven principally by population growth, but also by:

- Increased use of wood materials in construction, through rising demand for housing in developed and developing economies and emerging wood products driving increased substitution of steel and concrete with wood products.
- Policies that promote the use of bioenergy.
- Expansion of the use of cellulosic materials and novel compounds and fuels derived from biomass.

However, competition for available land represents a potential major constraint to future wood production. Increasing population will lead to expansion of urban areas and an increased demand for food production, and associated demand for agricultural land. For example, to ensure global food security, food production is expected to increase by 70%. However, the area of land of agricultural land available for food production appears to have peaked (Ausubel et al., 2013). Furthermore, the proportion of wood sourced from native forests is in decline and will decline further to ensure that global challenges of biodiversity loss and climate mitigation can be addressed. As a result a larger proportion of wood products will need to be sourced from plantation forests. However, plantation forests also have to compete for land within the agricultural and urban sectors.

Thus the challenge of sustainable land-use intensification requires the integration of forestry into the farming system in a manner that achieves a range of social, environmental and economic objectives including but not limited to, increased food security, increase the carbon storage within agricultural land, diversification of farm incomes and boosting agricultural productivity ("getting more from less"). As a result, agroforestry is central to sustainable landuse intensification and to achieving the United Nations Sustainable Development Goals (Garrity, 2004, Mbow et al., 2014, van Noordwijk et al., 2015).

Agroforestry research in Australia

Australia has a long and rich history of agroforestry research. A significant amount of R&D effort was conducted under the Joint Venture Agroforestry Program (JVAP). The JVAP programme was a collaboration between Rural Industries Research and Development Council, Land and Water Australia and Forest and Wood Products Australia that ran 15 years from 1993. A full overview of the programme can be found in Powell, (2009), although a brief synopsis of that program is presented here.

The Joint Venture Agroforestry Programme was established to:

- Provide national leadership, funding support and coordination of research, development and extension for agroforestry in Australia.
- Provide research that would address the aspirational goal for agroforestry to be commercially viable through either combined returns from private/public benefits or from having sufficient scale to be profitable in its own right.

- Enhance consultation with the industrial plantation sector, without being a principal funder of research, development and extension for that sector.

The JVAP programme priorities evolved from a number of issues emerging at the time. Throughout the seventies and eighties there was increased awareness of environmental degradation across agricultural areas, particularly in relation to salinity and loss of biodiversity. Tree planting was seen as an important tool in addressing some of these issues, however there was a lack of appropriate information to support decision making. Today agroforestry has an increasing role to play in managing landscape degradation and reversing environmental declines, enhancing food security, lifting farm productivity and adapting to and mitigating future climate change, and thus remains at the forefront of thinking in relation to the rehabilitation of agricultural lands. However, while the JVAP program recognised the value of introducing trees into the agricultural landscape, it also explicitly recognised the contribution that native forests on private land could make to supporting farm incomes. The initial priorities of the JVAP programme were focussed on understanding:

- Impediments to agroforestry including socio-economic impediments.
- Understanding growth and performance of species.
- Quantifying the effect of windbreaks on crops pastures and livestock.
- Using the results from research into windbreaks and species trials as input to research into the economics and marketing of farm trees to demonstrate financial benefits.

The JVAP programme resulted in a large body of work and a range of tools aimed at facilitating the uptake of agroforestry. These were reviewed by Powell, (2009) with 10 major themes emerging:

1. Profitability of farm forestry is generally marginal in high rainfall zones (ie rainfall > 600 mm) and largely unprofitable in low rainfall zones.
2. Emerging markets in carbon and energy may profoundly change the profitability of farm forestry.
3. Innovative processing technologies that enable high value products such as appearance grade timber to be produced from short rotation pulpwood or pruned sawlogs in higher rainfall areas.
4. Private native forests may supplement diminishing hardwood sawlogs supplies from public native forests, however there is a need to develop metrics to underpin environmental sustainability and enable participation in markets for environmental services.
5. Research conducted through JVAP enhanced understanding of the water and salinity effects of tree and shrub planting.
6. There are considerable costs associated with developing market based instruments for farm forestry, and most value may be associated with management of private native forests.
7. Northern Australia may be particularly prospective for farm forestry because of the current trend of increasing rainfall.
8. There remains limited understanding of farm forestry related knowledge, although a key activity arising from JVAP was the Australian Master Tree Grower program.
9. Research to elicit the key drivers and barriers that influence the behaviour of target audiences and can optimise time, resources and effort in developing farm forestry.

10. Engaging with key regional interests in consultation, planning, research, development, extension and on ground action, particularly for large scale plantings (Powell, 2009).

Powell (2009) summarised the key research, development and extension issues arising from the JVAP programme as:

- Potential of tree crops for carbon sequestration and biomass related industries.
- High value, farm-grown, wood based industries such as short rotation sawlogs and cabinet timbers.
- The social trajectories and relevant knowledge, attitudes and aspirations of farming and regional communities.
- Integrating the above knowledge into holistic assessments of the social, environmental and economic outcomes.
- Unlocking the potential of private native forests through improved market based instruments.
- Knowledge sharing between research programme investors and managers, researchers and research users to maximise the adoption of outcomes.

Agroforestry research in Australia has been relatively quiet in the years since the publication of Powell's synthesis of the JVAP programme. However, agroforestry is recognised as being an important contributor to securing the supply of national forest resources, with recognition in the Australian Forest Products Association 2016 policy paper (AFPA, 2016) and as part of the recommendations contained within the Forest industry Advisory Council (FIAC) strategy to expand the productive forest estate (Australia, 2016). The FIAC document recommended that the forestry industry develop a strategy for expanding the productive forest estate in strategic regional hubs through farm forestry, while also acknowledging that economic benefits of farm forestry may also flow via improved land values and on farm benefits such as shade and shelter for stock and crops, soil and water protection and other environmental benefits such as enhancement of biodiversity. While recognising the contribution that agroforestry can make to secure the national forestry estate, the report also recognised a number of key barriers to uptake and adoption of farm forestry enterprises including:

- Difficulties obtaining information about the commercial potential for farm forestry, including species selection and management.
- Information on species quantities and quality, including proximity to wood processing facilities and markets, and feasibility of forest operations.
- Private landholders often lack the tools and resources required for best practice forest management.

A recurrent theme in many of the reviews and policy statements related to expansion of agroforestry in Australia relates to a lack of tools or information related to:

1. Species selections and associated products.
2. An understanding of the commercial viability of agroforestry.
3. Lack of information on the drivers or barriers to adoption of agroforestry.
4. An inability to quantify both direct (commercial) and indirect (social and environmental) benefits of integrating agroforestry into the farming enterprise.

The current review seeks to address issues 1, 2 and 4. An understanding of the drivers and barriers to adoption is being addressed in a companion study (Fleming et al unpublished) through interviews with farmers and forest industry representatives. This review was supported by round two of the Rural Research for Profit funding scheme administered through the Commonwealth Department of Agriculture and Water Resources and aims to:

Review potential options for tree planting in high value modular agroforestry systems. The review will be quantitative and specific, where possible, and include the species options, their potential growth, returns and scalability. Options to be included in the review will include shelter, timber (both high value species and commodity timber), bioenergy, carbon, eucalyptus/other essential oil production, apiary, biodiversity, and high-value understorey species. The complementarity across the different options will also be explored.

This review predominantly focuses on synthesising information relevant for agroforestry systems in southern Australia, particularly in the higher rainfall (>600 mm) regions of Victoria and Tasmania. Farm forestry is ultimately about farmers choosing to commit resources to the development and maintenance of trees on their farms for a range of benefits that span commercial, environmental and socio-economic outcomes. While it is intrinsically recognised that the full suite of benefits may span this range of outcome domains, the review is structured around three main themes; commercial farm forestry, environmental farm forestry and integrating commercial and non-commercial benefits to maximise value and return to the farming enterprise. The report aims to review the evidence base underpinning the benefits of agroforestry with respect to both economic and environmental outcomes. Ultimately, adoption of agroforestry will be driven by the capacity of the chosen system to deliver demonstrable benefit to the farm enterprise (Pannell, 1999). Thus this report also explores existing frameworks for integrating the economic and environmental outcomes to capture the full range of benefits.

2 Direct economic benefits of agroforestry

Chapter Summary

- New commercial plantation establishment is very low and competition for suitable land is likely to increase.
- Agroforestry can fill an important gap in meeting increasing demand for forest resources into the future
- Commercial agroforestry, involving key commercial/plantation species, is profitable at a range of discount values, typically up to 8%.
- By considering tree economic value in isolation to the agricultural enterprise, economic analyses neglect complementarity and co-benefits and underestimate net present value to the farming enterprise.
- Economic returns on high value timbers are similar to commodity wood products but have higher market uncertainty, longer rotation lengths, and higher risk.
- Carbon farming markets and regulatory frameworks are still uncertain.
- Biomass has huge potential and existing biomass resources (forestry and agricultural activities) but significant logistical and processing challenges are likely to reduce viability.
- There is increasing interest in the development of high-performing *Leptospermum* spp. plantations for the production of medicinal honey.

2.1 Global and Australian context

A number of global trends are driving a resurgence in the potential for agroforestry to contribute to on-farm economic and environmental sustainability challenges, all related to sustainably meeting the challenges of rising populations and food, fibre and energy security. To address this sustainability challenge countries around the world have or are developing specific bioeconomic strategies. A bioeconomic strategy is defined as the "*the production of renewable biological resources and the conversion of these resources and waste streams into value added products such as food, feed stock, bio-based products and bioenergy*" (EU, 2012). It is believed that these emerging bio-economic strategies will underpin future demand for timber products and those that can meet regulatory demand for a sustainable feedstock are likely to prosper (Forests, 2015)

The global bioeconomy is increasing demand for;

- Timber and construction.
- Paper and packaging.
- Oils and plastics.
- Biofuels and energy.
- Food production.

At the same time it is well recognised that forest products sourced from sustainably managed planted forests can help achieve sustainability goals associated with;

- Climate adaptation and mitigation.
- Salinity control.
- Soil retention and protection.
- Land rehabilitation.
- Provision of habitat for biodiversity.
- Reducing pressure on remaining natural forests.

Thus, at least at a macro level the demand for forest products is likely to increase into the future and investment in timberland enterprises around the globe is increasing. However, despite these trends uptake and adoption of farm forestry in Australia is low and a major constraint on this adoption is that these global trends are unlikely to change the economics of farm forestry significantly.

Diversification of farm incomes via agroforestry is a recognised potential pathway to increase both and economic and ecological resilience of the farming enterprises (Prinsley, 1992), however the returns associated with agroforestry are often perceived as being low and the long time frames involved are considered a barrier to the implementation of the farm forestry systems (Powell, 2009). Thus embarking on a farm forestry venture for purely commercial returns requires careful planning and analysis. While the returns may often be marginal, direct economic returns may only be part of the considerations (see for example; Fenton (2010), Pannell *et al.* (2006)). Furthermore, there is often only a limited understanding of the range of potential markets associated with individual species, thus an improved understanding of the range of potential markets may assist with decision making and encourage adoption of agroforestry.

Recognising that agroforestry may have a range of potential benefits has long been highlighted as pathway to increasing adoption of agroforestry practices and increasing and diversifying farm gate incomes (Nair, 1993, Boutland *et al.*, 1992, Harrison & Herboln, 2008, Reid & Stephen, 2001). The potential for multiple markets both commercial and environmental have also long been recognised. For example; Moore (1992) stated;

"*the overall scale of tree planting likely to be adopted by Australian farmers to gain landcare (i.e measures to combat land degradation) benefits is very large. Such an area will produce a vast wood resource*"

Moore (1992) further stated that Australia should have a comparative advantage in wood production because trees will also provide substantial landcare and agricultural productivity benefits although also acknowledges that the resource will be widely dispersed and transport costs will be a major factor in the viability of any industry reliant on those wood products. To a large extent this opportunity is not being realised.

The aim of the chapter is to explore these potential direct economic benefits associated with agroforestry and to review the potential of common agroforestry species to service a range of potential markets. Specifically this chapter reviews current practices in generating the most common products or commodities: commercial wood production, the direction of current carbon

markets, potential for biomass industries for energy and fuel and other niche products such as oils and honey production.

2.2 Commercial Wood Production

2.2.1 Australian commercial forestry at a glance

In 2015-16 Australia's total commercial plantation area was approximately 1,974,770 hectares, of which softwood species accounted for approximately 53%. In 2015-16, Victoria had the largest total area of plantations (423,000 hectares) followed by New South Wales and Western Australia. Tasmania had 309,800 hectares. In 2015-16, there was only a small expansion of commercial forestry in Australia with all of the new establishment (1,415 ha) located in New South Wales. Long-term trends in plantation establishment are shown in Figure 1. Establishment peaked in 1999-00 and then in 2007-08 and has been low for at least the last 5 years. The majority of plantations (76%) in Australia are in private ownership. Public ownership accounted for 20.2% and jointly owned plantations only 3.6%. In 2015-16, 49% of the Australian plantation resource was owned by institutional investors, 4% by timber industry companies, 21% by farm forestry and other owners, 5% by managed investment schemes and 21% by government. Farm forestry and other private owners continue to represent a significant proportion of the Australian plantation resource.

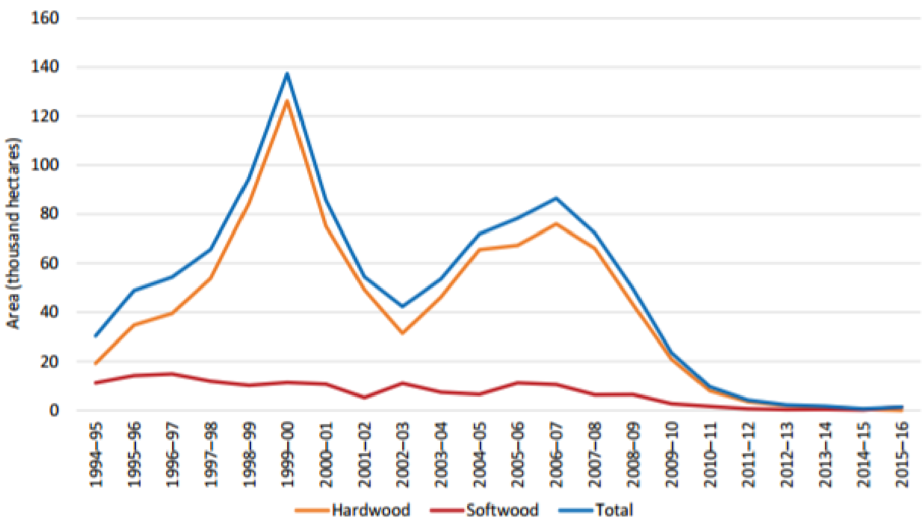

Figure 1 Plantation establishment in Australia over the period 1994 to 2016. Data for 1994-95 to 2005-06 are for calendar years and from 2005-2006 through to 2015-16 are for financial years (Source Figure 2, ABARES, http://data.daff.gov.au/data/warehouse/aplnsd9ablf002/aplnsd9ablf201705/AustPlantationStats_2017_v.1.0.0.pdf)

The Australian hardwood plantation estate is dominated by Tasmanian blue gum (57%, *E. globulus*), followed by shining gum (*E. nitens*) both of which are primarily managed for pulpwood production. The softwood resource is dominated by radiata pine (*P. radiata*) and southern pines (eg *Pinus caribaea, Pinus elliottii*). A breakdown of the major commercial tree species in the Victorian and Tasmanian NPI regions is given in Table 1.

Table 1 Major commercial tree species for the Tasmanian and Victorian national plantation inventory regions, 2015-16 (Source: Tables 9 and 10 Australian plantation statistics 2017 update)

REGION	TYPE	SPECIES	ha ('000)
Central Victoria	**Hardwood**	Tasmanian blue gum	31.7
		Shining gum	3.7
		Other eucalypts	2.2
		Other species	0.1
		Acacia species	0
	Softwood	Radiata pine	29.6
		Other pines	0.1
		Other species	0.3
Central Gippsland	**Hardwood**	Tasmanian blue gum	14.1
		Shining gum	10.7
		Other eucalypts	4.9
		Other species	0
		Acacia species	0
	Softwood	Radiata pine	61.2
		Other pines	0
		Other species	0.1
East Gippsland	**Hardwood**	Tasmanian blue gum	0.6
		Shining gum	6.2
		Other eucalypts	0.6
		Other species	1.2
		Acacia species	0
	Softwood	Radiata pine	48.6
		Other pines	0
		Other species	0
Green Triangle	**Hardwood**	Tasmanian blue gum	152.1
		Shining gum	0
		Spotted gum	0.1
		Other eucalypts	4.5
		Other species	0.6
		Acacia species	0
	Softwood	Radiata pine	174.5
		Other pines	0
		Other species	4.7
Murray Valley	**Hardwood**	Tasmanian blue gum	6.0
		Shining gum	0.5
		Spotted gum	0

		Other eucalypts	0.6
		Other species	0.1
		Acacia species	0
	Softwood	Radiata pine	187.2
		Maritime Pine	0.2
		Other pines	1.8
		Other species	0.5
Tasmania	**Hardwood**	Tasmanian blue gum	19.1
		Shining gum	208.2
		Other eucalypts	0.9
		Other species	5.7
		Acacia species	0
	Softwood	Radiata pine	75.5
		Other pines	0.2
		Other species	0.2

In 2015-16 around 97.7% of the softwood plantations were managed to produce sawlogs for sawnwood. Softwood logs produced from thinning operations and low quality parts of the stem were used to produce engineered wood products, landscaping products and paper products. In contrast 82.4 % of the hardwood plantations were managed for the production of pulplogs for products such as woodchips and paper (Downham & Gavran, 2017).

It is difficult to determine the contribution that farm forestry or agroforestry is making to the numbers outlined in Table 1. However based on the evidence available it would appear that agroforestry in Australia has been expanding, the National Forestry Inventory report of 2001 estimated that over 65,000 hectares had been established into farm forestry. By 2008 Farm forestry represented approximately 9% (155,000 ha) of the forest plantation area across Australia. In Victoria farm forestry represented 8.2 % of the total plantation area and in Tasmania farm forestry represented 9.2% noting that this excludes the contribution of private native forests (URS, 2008). These numbers have not been subsequently updated since this report however, the NPI 2016 report indicates that there has been an overall decline in the area of plantations in Victoria over the last five years of 1.7% and a very slight increase in Tasmania of 0.2%. The proportion of plantations in farm forestry and other private owners has increased from 13% in 2004-05 to 21% in 2014-15. This large change in ownership was largely driven by the decline in managed investment schemes (NPI, 2016).

2.3 Commercial agroforestry

Given the potential reduction in available agricultural land and increasing demand for both food and forest products, agroforestry is seen as a viable alternative to large scale plantation development (AFPA, 2016, Australia, 2016). However, commercial agroforestry is a long-term land use option with return periods of twenty to thirty years. Thus decisions on the potential of any

farm forestry operations need to consider the economics of the operation, i.e. the opportunity cost, market opportunities, regional conditions (such as distance to processing facilities) potential changes to economic conditions and trends in emerging markets (Polglase *et al.*, 2008b).

Commercial agroforestry in Australia can take many forms; plantations on farmland, woodlots, timber belts, alleys, wide spaced tree plantings and native forests, and a considerable amount of effort under the Joint Venture Agroforestry Programme examined this potential. Farm forestry may be taken on by the enterprise or may involve large scale plantings under joint venture arrangements or the leasing of farmland to forestry companies (Herbohn *et al.*, 2008). These models may reduce the risk to the farm enterprise as the management of the plantations would be conducted externally, furthermore the farmers may receive a direct annual financial return based on the lease costs of the land (5-9% land cost). There are a number of useful publications that outline the types of considerations required (Table 2) and it is not the intent to repeat these here. However, these generally cover the broad range of considerations required for developing farm forestry operations from planning, financial analysis, site selection, species selection and harvesting and are targeted at farm foresters.

Table 2 Resources relevant to the range of options available for farm forestry.

RESOURCE	URL
Davidson NA, Volker P., Leech M, Lyons A and Beadle C (eds) (1997) Farm Forestry: a technical and business handbook. University of Tasmania, Hobart.	http://www.utas.edu.au/plant-science/resources/publications/farm-forestry
Lambeck R, Stirzaker R, Abel N, Fargher J, Cleugh H, Thornburn P, Baxter J, Prinsley R, Reid R, Prosser M, Schmidt C, Revell G and Campbell A (1997) Design principles for farm forestry: a guide to assist farmers to decide where to place trees and farms plantations on farms. Rural Industries Research and Development Corporation, Canberra, Australian Capital Territory, Australia.	http://www.agroforestry.net.au/main.asp?_=publications
Reid R and Stephen P (eds) (2001) The farmer's forest: multipurpose forestry for Australian Famers.	http://www.agroforestry.net.au/main.asp?_=publications
Harper, R. J. et al. Site Selection for Farm Forestry in Australia. (Rural Industries Research and Development, Canberra, 2008).	https://rirdc.infoservices.com.au/downloads/08-152
Marcar, N.E.; Crawford, D.F.; Leppert. P.M.; Jovanovic, T.; Floyd, R.; Farrow, R. (1995) Trees for saltland: a guide to selecting native species for Australia. Canberra: CSIRO Forestry and Forest Products.	https://publications.csiro.au/rpr/pub?list=BRO&pid=procite:86249b73-33aa-486b-a34a-4b142a92bd22

While direct economic benefits of agroforestry have been widely discussed, surprisingly there have been relatively few direct financial analyses of the potential of agroforestry projects in Australia (Hean *et al.*, 2000), despite findings by Pannell (1999), that a major impediment to agroforestry adoption in developed countries is the lack of evidence that agroforestry is in fact more profitable than the existing farming system. This is in contrast to the situation internationally, particularly developing countries where there have been a significant number of formal benefit cost analyses. For example, Current *et al.* (1995) reviewed 21 agroforestry case

studies in South America and found that many agroforestry practices are profitable even at very high discount rates of up to 20%.

Kirby *et al.* (1993) reviewed the limited literature that had examined profitability of agroforestry in Australia finding that agroforestry compared favourably with agriculture at discount rates of 8%, noting however that while the evidence suggested that agroforestry was generally profitable there were a paucity of data for situations were agroforestry was unlikely to be profitable (Table 3). Malajczuk *et al.* (1996) examined pine agroforestry in the wheat sheep belt of Western Australia, and demonstrated that pine agroforestry could be more profitable in the long run than conventional agriculture, although in this study the system under examination was a 'model' farm grazing merino weathers for wool production. The agroforestry systems examined included unthinned *Pinus radiata*, thinned *P. radiata* at a range of planting densities, and thinned and unthinned *P. pinaster* planted at low densities. The average internal rate of return (Table 4), was 9.9, but ranged from 8.4 to 17.18 depending on the scenario modelled (Malajczuk *et al.*, 1996). Net present values were positive for all scenarios at discount rates up to 7%, negative for only 2 scenarios at 9% (high density and thinned and unthinned *P. radiata* plantings) and largely negative at discount rates of 11% except for the *Pinus pinaster* plantings. Additionally, Malajczuk *et al.* (1996) found that net present values were also sensitive to both sawlog and wool prices. They found that with a 25% decline in wool prices, agroforestry was viable at discount rates up to 8%, where the agriculture was not viable. However if log prices dropped 25% and wool increased 25% agroforestry is still viable at discount rates of up to 8%.

Campbell White and Associates and Black (1999) analysed the economic benefits associated with farm forestry using ten case studies across southern Australia. They note that the configuration of forestry on-farm was closely aligned to the motivating factors. Those more interested in financial returns typically adopted block configurations, while those with a mainly environmental motivation made efforts to integrate the trees into the farm landscape in a manner that maximised environmental benefits, although trees were actively managed to maximise future commercial potential (e.g. using thinning and pruning). The study noted that in eight of the ten case studies, forestry had the capacity to generate significant returns on investment, greater than 25% above that which have resulted without tree planting. However the discount rate used to substantiate this claim was quite low in comparison to other studies, at 5%. Furthermore the study highlighted the importance of choosing land with the lowest opportunity cost as in one of the case studies, forestry was established on highly productive land where the value derived from the beef grazing would have been higher.

Fritsch and Hudson (2008) examined the economic returns of farm forestry using six case studies across southern Australia including a mixed farm enterprise in Western Australia, private native forests, north coast of NSW, blue gum forestry lease in SW Victoria, grazing, shelterbelt and sawlogs in Victoria, grazing and forestry in SE Victoria and a mixed farm enterprise in Tasmania. The study found that on a standalone basis it was only short term pulp wood rotations in regional areas with an established commercial forestry industry that outperformed agriculture-only returns on a NPV basis. Standalone forestry targeting long rotation sawlogs produced financial returns that were not competitive with the alternative agricultural enterprise on an NPV basis. In this case study an investment in sawlogs would have performed better in the equity market. They concluded that to improve viability of sawlog farm forestry would require development of markets for pruning's, and thinning to enable costs to be recouped earlier in the rotation.

Overall, integration of trees into the landscape in the study of Fritsch and Hudson (2008) resulted in lower risk (discount rate 6.3%) net present values that were superior to livestock only options. However at higher discount rates of 20%, returns from agroforestry were inferior to those from livestock only. Increased diversity, erosion control, aesthetics, protection from extreme weather and personal satisfaction were seen by landowners as adequate compensation for the reduced returns.

Fritsch and Hudson (2008) make a number of recommendations to improve to financial viability of farm forestry (particularly sawlogs) these include:

- Development of ways to generate income earlier in the rotation to offset costs or to demonstrate integrated whole farm benefits.
- Increased effort required to capture historical prices and measured growth rates for farm woodlots
- Improved understanding of farmers in financial tools such as NPV so that they are better equipped to make investment decisions and understand the risks.

Table 3 Australian studies addressing benefit costs analyses of Australian agroforestry systems

STUDY	METHOD	KEY FINDINGS	SCENARIO
Ferguson and Reilly (1978) cited in (Kirby *et al.*, 1993)	NPV	Both systems profitable at a discount rate of 8%	Two systems examined improved pasture and beef, native pasture and beef with pine agroforestry on the south coast of New South Wales
Learmonth and Rabette (1978) cited in (Kirby *et al.*, 1993)	NPV	Agroforestry enterprise had higher NPV than either full-scale pine enterprise of full scale merino enterprise	Integrated Pine and Merino enterprise in Ballarat Victoria
Gisz and Sar (1980) (Kirby *et al.*, 1993)cited in (Kirby *et al.*, 1993)	NPV	Prime lamb enterprise more profitable than agroforestry enterprise at discount rates >9%	Prime lamb/*P. radiata* enterprise Tarago New South Wales
Garland, Fisher and Greig (1984) cited in (Kirby *et al.*, 1993)	NPV	At discount rates of 12 and 20% agriculture, agroforestry and woodlots all profitable	Prime lamb enterprise Carngham, Victoria
(Malajczuk *et al.*, 1996)	NPV/IRR	Profitable at discount rates to approximately 8%	Theoretical study, Merino grazing for wool production with pine agroforestry
(Campbell White and Associates & Black, 1999)	NPV/BCR	NPV gain of $149K in with/without trees scenario and BCR of 3.93	Sheep grazing for meat and fine wool, integrated with blocks of blue gum forestry in the SW of Western Australia
		NPV gain of $161K in with/without trees scenario, BCR 2.35	Beef grazing integrated with *P.radiata* and *E. globulus* forestry in Penola SA
		NPV in with/without trees scenario was - $31K, participants believed that incorporating externalities would provide a positive BCR of 1.31	Prime lambs, wool and beef cattle with commercial timber production in SW Victoria. The forestry is mixed eucalypt and Acacia plantings as well as environmental plantings

		NPV in with/without trees scenario was $148K, BCR of 17.3	Mixed farm grazing cropping with native and plantation forestry in NE Tasmania
		NPV in with/without trees scenario was -$313K, BCR not available. High productivity of the land drives down the profitability of the forestry operations	Beef cattle fat lambs and farm forestry in the Gippsland region of SE Victoria, forestry included plantations of *E. regnans* and *P. radiata*
		NPV in with/without trees scenario was $79K, BCR of 4.54	Merino wool enterprise, incorporating spotted gum, *P. radiata*, *Grevilia robusta* (Silky oak)
		NPV in with/without trees scenario was $1K, BCR of 2.28	Beef grazing converted to macadamia farms near Lismore in NSW. The forestry component included mixed plantings of eucalypts and high value rainforest trees
		NPV and BCR not available	Beef production in SE Queensland, with forestry including mixed eucalypt species and specialty species such as Hoop and Bunya pine
		NPV in with/without trees scenario was $15K, BCR of 1.7	Mixed grazing cropping (sheep/lupins and wheat, forestry includes eucalypt and saltbush for salinity control and Oil mallees in SW western Australia
		NPV in with/without trees scenario was $54K, BCR of 3.47	Mixed merino and cropping enterprise, forestry predominantly blue gum but smaller areas of *P. radiata* and mixed species
(Fritsch & Hudson, 2008)	NPV/IRR	Forestry had higher NPV (6.5%) and risk adjusted rates (20%). Farm forestry was seen as a superior use of the land under the prevailing market conditions	Beef grazing/forestry (bluegum pulp) WA
	Historical analysis of returns	Native forestry returns were on average lower ($10.98 ha^{-1} yr^{-1}) than returns from grazing ($12.81 ha^{-1} yr^{-1}). However, analysis revealed that without the forestry the whole enterprise would struggle to meet costs	Private native forestry/beef enterprise north coast NSW
	NPV	The lease produced positive NPV at risk free rate but underperformed at the risk adjusted rate	Blue gum forestry lease SW Victoria, no competing agricultural enterprise
	NPV	The NPV associated with the forestry itself was negative at both risk free and risk adjusted rate, however, increased lamb survival	Grazing and shelterbelt, prime lands on improved pasture, with mixed sawlogs

		resulted in positive NPV at both return rates	
	NPV	The forestry generated positive NPV at 6.5% but at rates below market returns. NPV was negative at risk adjusted returns. The integrated agribusiness NPV were higher albeit with a similar trend	Grazing and woodlots, prime lambs
	NPV	The forestry returned a positive NPV at the risk free rate but could not meet the higher risk adjusted rate, however from a whole farm perspective the woodlots returned higher profits than currently achieved by livestock	Mixed farm enterprise in SE Tasmania,

*** Note that economic analyses of this nature are very sensitive to underlying assumptions, these are not reported in this table and should be considered before any decision is made to pursue a farm forestry enterprise*

In a summary of the 15 years of the JVAP programme, Powell (2009) found that the key determinants of profitability in Australia are forest growth rates, transport distances and product prices. Powell concluded that in the high rainfall zones (i.e > 600 mm) profitability of farm forestry is marginal for products other than pulp wood grown in areas with existing processes, largely due to the lack of developed markets for prunings, thinnings and other environmental benefits. Furthermore the analysis of (Campbell White and Associates & Black, 1999) highlighted the importance of selecting land for forestry with the lowest opportunity cost. In medium to low rainfall zones (i.e < 600 mm) low growth rates and generally greater distances to market have been key constraints on the expansion of agroforestry, despite the considerable amount of work done by the Australian Low Rainfall Tree Improvement group to select faster growing Acacias, hardwoods, pines and oil mallees (Bush *et al.*, 2009).

While recognising that the matrix of agroforestry opportunities by region is very large Polglase *et al.* (2008b) conducted a national prospecting exercise of regional opportunities for agroforestry and found that market opportunities and growing opportunities in many regions for sawlogs (softwood and hardwood) and wood chips for export ranged from medium to high (Table 4). This study specifically examined the economic benefits associated with of a number of agroforestry scenarios, including hardwood and softwood sawlog, pulp wood, bioenergy plantings, integrated tree processing plantings, environmental carbon plantings, hardwood and softwood carbon plantings and oil mallees. However, this national scale assessment was conducted at a relatively coarse resolution ($1km^2$) and so the results are not easily transferrable to the scale of the farm enterprise. A significant outcome form this work was the compilation of a series of spatial layers and the calibration and validation of growth models for a large range of prospective agroforestry species, although it acknowledged that significant challenges remain including information on growth and productivity for a range of species, an improved understanding of understanding of breeding and silvicultural management to maximise growth rates and a better understanding of potential impacts of climate change on growth and productivity.

Table 4 Rating of NPI regions according to market opportunity, growing opportunity for sawlog and woodchip regimes according to Tasmanian and Victorian National Plantation Inventory Regions, L = low; M = medium and H = high. Source (After Polglase *et al.,* 2008b).

REGION	MARKET OPPORTUNITY +GROWING OPPORTUNITY		
	Softwood logs	**Hardwood logs**	**Wood-chip exports or pulpwood**
NW Victoria	L	L	L
Central and W Vic	M	H	M
Green Triangle	M	H	H
Gippsland	M	H	H
Tasmania	M	H	H

While the analysis of Polglase *et al*., (2008b) highlight strong prospects for commercial tree growing on farms, they caution that the results are regional in nature and that they require greater ground-truthing to test the underlying assumptions. While there have been significant changes in market conditions over this period, the modelling of species growth rates is unlikely to have changed much, thus there is significant opportunity to update the analysis with new market conditions as they emerge

2.3.1 A note on specialty timbers

The farming of high value specialty timbers are subject to all of the financial considerations outlined above, however they have additional uncertainty due to a lack of data on market conditions, transparency in pricing and specifications and processing facilities. While a number of case studies outlined above include plantings of specialty timbers, typically Acacias and conifers, it is difficult to separate the economic benefits attributable to the growing of these specialty timbers from the broader economic analysis. While some specialty timber products can attract high prices e.g. for tone woods, demand is typically low and product specifications are often very tight (Morrow, 2007). Similarly Powell (2009), concluded that although there were many good prospects, especially for cabinet timbers in Queensland, many growers were experiencing difficulties in obtaining stumpage prices that would justify harvesting, and that there was a lack of critical mass of farm sawn and dried timber for sale into niche markets for high quality timber. In many of the studies outlined in Table 3 plantings were typically small in area, (few ha's) and detailed analysis was not possible due to the uncertainty in market conditions. However, the case studies highlighted that specialty timbers typically have longer rotations than those commodity timbers and many highlighted the importance of achieving additional benefits to justify returns throughout the lifecycle of the rotation.

Detailed analysis of economic returns for specialty timbers are few in Australia. Cavana and Glass (1985) conducted an analysis of the economic outcomes of growing specialty timbers in New Zealand compared to *P. radiata*. The scenarios assumed that all species were grown to produce high quality sawn logs, and included an analysis of internal rates of returns and net present values

at 5 and 10% discount rates. Internal rates of return for each species were; radiata pine 4.0-9.9%, cypress 4.0-8.0%, eucalypts 3.1-7.5%, blackwood (*Acacia melanoxylon*) 5.3-8.0 % and black walnut 3.8-5.6%. The analysis suggests limited advantage to growing a range of specialty timber. They conclude that non-tangible benefits need to be included to make growing these timbers attractive relative to radiata pine. However, since that study there has been a growing domestic market for blackwood in New Zealand, potentially changing the economics to some extent. Furthermore specialty timbers will be increasingly difficult to source from native forests as larger areas of forests are reserved for conservation purposes.

Of the high value specialty timbers in Tasmania and Victoria most knowledge is related to *Acacia melanoxylon* (Brown, 2004), although detailed economic analysis remains rare. Thorrold *et al.* (1997) examined the financial viability of three agroforestry options including blackwood for a typical grazing enterprise on the north Island of NZ. Planting *A. melanoxylon* in sheltered gullies and riparian areas was profitable under the cost and labour assumptions used in that study, although this specialty timber was not as profitable as *P. radiata* plantings, largely due to the higher silviculture inputs required. However, the analysis did not include formal economic evaluations such as those outlined in Table 3. This finding is consistent with a summary of the economic evaluation by Nicholas and Brown (2008). They observed that in New Zealand economic evaluations of blackwood plantings usually have an internal rate of return of 5-8%, which are typically lower than *P. radiata* but there was considerable uncertainty in the economic evaluation because of high levels of uncertainty in the data.

Bush *et al.*, (2016a) reviewed forestry options for low rainfall regions, and noted that while the research in dryland forestry options has been conducted for decades, the tyranny of distance has probably constrained the development of dryland forestry operations. Bush *et al.* (2016a) note that an emphasis on higher value low volume products will be important. In southern Australia, breeding programs have resulted in significant capacity to produce high quality germplasm for a number of species including *C. maculata*, *E. cladocaylx*, *E. occidentalis*, red ironbarks and mallee species. While economic analysis is largely absent for most cases trials have been established and are still in good condition providing a good platform for further research. The review highlights that for the most prospective specialty timbers in low rainfall sites:

- There is an existing suite of reliable dryland species that have been well tested, although testing a greater range of dryland conifer species would be beneficial.
- Many of the trials established in the 2000's are now at an age that is suitable for growth and analysis of wood properties.
- Future R and D should be focussed on the development of higher value products rather than growth and silviculture because of the inherent difficulties associated with transport costs and water deficits.
- There is a requirement to better understand the impacts of extreme climatic conditions on species responses.
- Further policy development is required to bring more investment certainty.

Careful consideration of the motivations and drivers for farmers to establish tree plantations are even more important for growing specialty timbers, as is a consideration of potential value adding opportunities. There have been a number of reviews that address species selection, products and

potential value adding (Table 5). While useful from a biophysical perspective, these have not been subject to detailed economic evaluations.

Table 5 Existing reviews of species suitability and selection.

AUTHORS	TITLE	NOTES
Morrow, (2007)	Evaluation of Australian timbers for use in musical instruments	Presents an evaluation of Australian native timbers for use in stringed instruments. The review covers wood properties and tonal qualities and identifies species with potential and availability
Nicholas & Brown, (2008)	Best Practice with farm forestry Timber Species No 4: Blackwood	Detailed overview of the potential of *Acacia melanoxylon* as a farm forestry species including silvicultural and economic evaluations for New Zealand situations.
Clarke *et al.*, (2009)	Trees for farm forestry: 22 promising species. Canberra.	Profiles 22 species suitable for a variety of agroforestry outcomes with detailed descriptions of environmental requirements and potential market opportunities
Bennell *et al.*, (2009)	Evaluating agroforestry species and industries for lower rainfall regions of south east Australia	Details the outcomes of an agroforestry species selection and evaluation process aimed at identifying Australian native species with potential for development as broad scale commercial woody biomass
Hobbs *et al.*, (2009)	Potential agroforestry species and regional industries for lower rainfall southern Australia	Identifies agroforestry and fodder species with the greatest potential for development as broad scale commercial woody biomass crops in the lower rainfall regions of southern Australia
Hobbs, (2009)	Review of wood products, tannins and exotic species for agroforestry in lower rainfall regions of southern Australia,	Reviews wood products and tannin potential from a range of low rainfall tree species both native and exotic
Bush *et al.*, (2016b)	Review of dryland plantation forestry opportunities in Australia	Reviews research on low rainfall forestry with recommendations made for most prospective species

2.4 Carbon sequestration

Carbon sequestration through agroforestry has long been viewed for its potential to improve on-farm profitability while simultaneously addressing a range of natural resource management and environmental challenges. In Australia the Clean Energy Regulator runs an emissions reduction fund that provides incentives for a variety of emission reduction activities. To be able to claim carbon credits through the emissions reductions fund, the activity must have an approved methodology. To date approved methodologies include the dedicated planting of trees and the restoration and protection of existing native vegetation. Plantations established for harvesting have been excluded from the scheme due to a lack of methodologies, until recently (see below for details on the new harvested-trees methodology). Despite this, the potential for new forestry

plantations to be driven by carbon credits is heavily dependent on the price of carbon and over the course of three ERF auctions held thus far the price of carbon has declined from \$13.95 t^{-1} CO_2e in April 2015 to \$10.23 t-1 CO_2e in April 2016. Recent analyses also suggest that if carbon offset investments target marginal lands, carbon prices required for economic viability are >\$18 t CO_2 equivalent at a discount rate of 8% (Paul *et al.*, 2013a).

To be effective at mitigating CO_2 emissions into the atmosphere and potentially aiding landscape restoration, the long-term planning and maintenance of carbon forestry projects is critical and should consider planning horizons longer than 100y. Every 1 M ha of carbon sequestration plantings would offset 1.4% of Australia's year 2000 emissions (7.4 Mt CO_2^{-1}) if an average rate of sequestration is achieved (Polglase *et al.*, 2013). While several economic analyses suggest economic benefit for landholders is limited (this is highly dependent on assumptions surrounding market conditions, growth rates and opportunity/on-farm costs) (Polglase *et al.*, 2011), carbon markets have been identified as the most likely source of income for environmental services from forestry in the near future (Matysek & Fisher, 2016). Furthermore, financial incentives have also been shown to be an important motivator farmers. Defenderfer (2010), in a survey of Tasmanian farmers, found that financial gain was the main motivator of actions to increase storage of carbon on farms, ahead of social responsibility, biodiversity benefits and personal interest. Polglase *et al.* (2008a) concluded that carbon sequestration in permanent plantings offers some potential economic advantage over industrial tree plantations because: the absence of harvest and transport costs, the lack of constraints associated with the need to be located close to processing facilities and the potential flexibility to avoid large concentrated plantings that increase drought, fire, pest and storm risk (Polglase *et al.*, 2008a). Impacts on catchment water yield could also be avoided through careful catchment planning and selection of sites that limit down-stream water harvesting and environmental flow (Benyon & Polglase, 2009, Polglase *et al.*, 2008a).

The Carbon Farming Initiative (CFI) is the Australian Government's legislated offset scheme. Since 2014 the CFI has become part of the Emissions Reduction Fund that operates as a reverse auction scheme (Parliament of the Commonwealth, 2014). This policy puts the onus on the landholder to formulate a project detailing the activities that will be undertaken, such as the tree planting project and the required price per tonne of emissions reduction or sequestration associated with the project. Specifically the current CFI under the environmental plantings methodology (from July 1st 2015) defines farm forestry as:

- Permanent plantings, whereby no commercial harvesting is permitted.
- Harvested plantations, if grown in regions with mean annual rainfall > 400mm, the planting area must be < 100 ha or 30% of the property (whichever is smaller); if grown in regions with mean annual rainfall < 400mm, the planting area must be < 300 ha or 30% of the property (whichever is smaller). Harvesting is permitted within the management regime, trees after harvesting must be re-established under a management regime cycle.
- Commercial harvesting of plantations can only occur for stands either: established on or after the 1 July 2010, if it is a new farm forestry project, or between 2001 and 30 June 2010 if it is an accredited forestry project under the Greenhouse Friendly™ initiative of the Australian Government.
- Trees must be allowed to reach 2m height and achieve 20% crown cover.

- Disturbances such as fire must be managed to allow the plot to recover to previously reported values.

Under the current criteria for farm forestry in the CFI, smaller plantings in higher rainfall zones (>400 mm) are permitted, and would allow small plots of timber and wood products to be harvested. Timber and wood production is likely to be viable in areas > 600 mm if the displacement of prime agricultural land is minimised (Polglase *et al.*, 2011). The current reporting requirements of the CFI are relatively onerous and extensive, especially for farmers with little forestry experience. Additional costs for specialist assistance to manage carbon accounting using carbon aggregator companies are likely to be required and will reduce return on investment for the landholder.

The absence of wood products and soil carbon from carbon accounting methods in the CFI legislation has reduced the economic viability of carbon plantings. These regulatory constraints are thought to have hampered major investment in long rotation, commercial forestry as projected by Burns *et al.* (2011) and Centre for International Economics (2012) and has been seen as a major economic impediment for the viability of timber and pulp production for industrial plantations (Paul *et al.*, 2013b) and to a lesser extent farm forestry (Paul *et al.*, 2013a). Paul *et al.* (2013b) concluded that recognising carbon sequestration potential from wood products from industrial plantations is likely to capture an additional 7% of the total amount of sequestered carbon and, under conservative assumptions, increase the net present value between 21 and 30% (for discount rates of 5 and 8% respectively).

Given the low uptake and expansion of carbon forestry in higher rainfall regions (>600mm) there are still significant challenges for establishing viable carbon plantings in these more productive landscapes (Mitchell *et al.*, 2012). In general, carbon forestry faces considerable challenges in relation to; regulatory uncertainty, technical barriers in incorporating carbon farming methods and protocols into the farm enterprise, social and cultural preferences around land use, lack of understanding by investors/financiers and lack of scale that limits carbon farming intermediaries/third party investors (carbon farming companies) and industry investment in R&D (Mitchell *et al.*, 2012).

Carbon forestry projects that can capture multiple or co-benefits that improve carbon sequestration, biodiversity, water and nutrient management and agricultural production are often seen as key drivers for adoption (Dumbrell *et al.*, 2016, Torabi *et al.*, 2016). The analysis by Paul *et al.* (2013a) in three case study regions assumed additional economic benefit of belt plantings through mitigation of soil erosion, dryland salinity and the provision of shelter for crops and stock at a conservative estimated price of $18 ha^{-1} yr^{-1}. Based on this assumption, they found that belts tended to be more economically viable than block plantings (Paul *et al.*, 2013a), however block plantings can also provide considerable on-farm co-benefits. Crossman *et al.* (2011) identified target areas in the cropping and grazing zones of South Australia where additional landowner payments for restoring critical habitat could be used to improve biodiversity outcomes in carbon plantings. Under six carbon price scenarios, they found that direct annual payments of between $7 and $125 ha^{-1} yr^{-1} was sufficient to augment economic returns from carbon market payments and encourage plantings that would have demonstrable outcomes for biodiversity values (Crossman *et al.*, 2011). Meta-analyses of mixed species tree plantings *versus* monoculture carbon plantings suggest similar and sometimes higher above- ground growth increments in mixed plantings that

can potentially provide additional services to the farming landscape (Hulvey *et al.*, 2013). Thus increasing functional and structural diversity in carbon plantings may not impose large penalties on tree growth rates, and potentially carbon sequestration rates. Broadening the objectives of carbon farming beyond a narrow focus on carbon sequestration is likely to help avoid perverse outcomes or disbenefits for the landholder and society – increased land clearing and monocultures (Lindenmayer *et al.*, 2012). Undoubtedly there is enormous potential for maximising the values of carbon forestry through appropriate landscape design, scale, configuration and composition – many of these components will be discussed in Chapter 4.

Another important element of carbon farming in contrast to other forms of primary production is the reduced management flexibility with regard to a long-term (>100 yr) investment of farm land and resources and the large amount of perceived or realised uncertainty. Reeson *et al.* (2015) showed that losing land management flexibility increased the opportunity cost of farm forestry and that , combined with uncertainty in carbon prices can delay adoption and slow the rates of adoption overall. The presence of incentives for co-benefits, namely biodiversity is likely to help overcome some of these barriers to adoption (Torabi *et al.*, 2016). Given the appropriate policy and crediting rules that recognises the value of the additional environmental benefits carbon farming may become more attractive.

2.5 Biomass

An overwhelming theme of the economic analyses outlined in section 2.3 was that value to farmers could be increased if there were commercial markets developed for prunings, thinnings and other residues. It is suggested that agroforestry has the potential for large scale biomass production to provide a range of products, including biomass for electricity generation, biofuels, oil production for polymers and essential oils from medicinal and perfume markets (Mendham *et al.*, 2015). As the world moves to reduce reliance on fossil fuels and ensure energy security for all (Sustainable Development Goal #7), energy and oil production from biomass has long been viewed as part of the solution to reducing reliance on fossil fuels (Rothe *et al.*, 2015). However, the transition is not without problems. In both the US and Europe policies to promote the use of biomass for fuel and energy have led to perverse outcomes such as increased volatility in food prices, and even exacerbated clearing for the development of biofuels (Bailey, 2013a, Repo *et al.*, 2012). There is long identified potential for agroforestry to address some of these sustainability concerns associated with the production of bioenergy feedstocks (Stucley *et al.*, 2004, Bryan *et al.*, 2008, Sharma *et al.*, 2016). However, production costs remain largely uncompetitive with traditional fossil fuel alternatives.

Biomass energy currently represents approximately 1% of the Australian energy market. This is less than the global OECD average of 2.4 percent which suggests that there is significant potential for new investment (CEFC, 2015). Forest residues have potential as feedstocks for bioenergy, particularly export of wood pellets, given the low cost and the readily available feedstock, however the profitability is driven by transport costs, plant growth rates and project scale. The CEFC, (2015) estimates that the investment opportunity in biomass and energy from waste opportunity is between 3.5 and 5 billion dollars to 2020. Currently 124 MW of the total Australian

812MW of installed bioenergy generation capacity is sourced from forest residues with the leading opportunities for future investment including:

- Generating electricity from plantation forest residues using direct combustion technology to offset grid electricity consumption.
- Producing biomass pellets for co-firing in coal fired power plants.
- Exporting biomass pellets, particularly to countries in south east Asia, that have policies to promote biomass a renewable energy feedstock (CEFC, 2015).

There have been a number of assessments of biomass energy potential in Australia (Crawford *et al.*, 2016, Farine *et al.*, 2012). Stucley *et al.* (2012) provide a comprehensive review of the biomass opportunities in Australia in a broad ranging review that covers a range of topics including the thermal properties of biomass feedstocks, sustainable biomass supply chain logistics and harvesting. That review is far more authoritative than can be covered here. Stucley *et al.* (2012) highlight the complexity of bioenergy as a topic as it encompasses multiple feedstocks from agriculture fisheries and forestry, it produces electricity, heat and liquid fuels with potential for future co products and uses a range of technologies to produce those outputs. Farine *et al.* (2012) conducted a national scale assessment of a range of biomass feedstocks, applying constraints on avoided clearing of native vegetation, minimising impacts on domestic food security, retaining residues to protect soil and minimising impacts on local processing industries by diverting only the export fraction of pulpwood to bioenergy. They found that cellulosic biomass from both agriculture and forestry could produce 9.4 GL ethanol yr^{-1} or 35 TWh yr^{-1}, approximately 15% of electricity consumption in Australia at the time of the study. In particular, short rotation coppiced eucalypt crops could provide 4.3 GL ethanol yr^{-1} or replace 20.2 TWh yr^{-1} of electricity. Crawford *et al.* (2016) estimates that forest plantations could currently provide 10.9 MT per year of lignocellulosic biomass, and noted that new plantings of short rotation trees would drive an increase in supply total supply from the current estimate of 80 MT yr^{-1} to potentially 110-155 MT yr^{-1} over the next 20-40 years, but notes that while the opportunities are large, a greater investment into understanding to opportunity costs is required, and this is particularly true at the farm scale.

In Tasmania Rothe *et al.* (2015) estimated that potentially 1750 Kt yr^{-1} of forest residue could be available for energy generation corresponding to 33% of Tasmania's current energy demand. Of this approximately 1250 Kt yr^{-1} could be sourced from existing plantations. Thus, while there is large potential, Rothe *et al.* (2015) also note that about 400 Kt yr^{-1} is currently used for producing energy, with domestic firewood for heat production being the largest consumer. There are currently no large scale facilities for producing energy from biomass in Tasmania.

Economic valuations of biomass for energy at the farm scale are few. Bryan *et al.* (2008) conducted an economic and environmental assessment of the potential biomass production in the south Australian River Murray corridor, finding that there was significant potential for biomass production (~58% of the dryland agricultural area) producing 3 million tonnes of green biomass per year with a net present value of 88 million dollars over 100 years. Bennell *et al.* (2009) however notes that cost of supply is a major constraint on the competitiveness of electricity production, particularly when compared to coal fired generation. This can be somewhat overcome from the co-production of other products such as eucalypt oils and activated carbon such as was planned at the Narrogin pilot plant in WA or where small scale generators in regional areas can

compete with energy sourced elsewhere and/or co-generation can improve the efficiency of generation.

The Stucley *et al.* (2012) review is a comprehensive overview of the range of considerations required for the development of biomass energy in Australia. The role of agroforestry in the supply of feedstocks has received little attention in systems other than Mallee and Pongamia. These are summarised at biomass producer.com.au (http://biomassproducer.com.au/producing-biomass/biomass-types/trees/#.WTtpOeuGOJ, viewed 10/06/2017). Hobbs *et al.* (2006) explored the profitability of biomass industries in the upper south east of South Australia and found that several of the industries they explored had returns competitive with existing cropping and grazing systems in the area, but were reliant on the development of new infrastructure.

Brown and Coote (2017) note in an opinion piece for The Conversation (https://theconversation.com/burning-wood-an-opportunity-for-renewable-power-and-heat-43786, viewed 10/06 2017) that in Europe, feedstocks for the relatively advanced bioenergy network, are largely sourced from residues of commercial operations to produce timber or fibre from wood. Dedicated woodlots and short rotation woody crops are a relatively small component of the feedstock demand. Given the huge relatively untapped potential of existing plantation feedstocks in SE Australia e.g. Rothe *et al.* (2015), it is difficult to see market opportunities for biomass only woodlots to develop. Regardless of that outcome on-farm use of biomass energy remains possible (e.g. for production of heat) and biomass to generate energy (Stringfellow *et al.*, 2011, Brooksbank *et al.*, 2014). Bennell *et al.* (2009) highlight the market niches where electricity from biomass may be competitive

- Small scale biomass plants.
- Situations where a range of products are produced from biomass raw materials.
- Where co-generation can improve efficiency of generation.
- Where market premiums such as the sale of renewably sourced power can be used to increase the value of renewable energy.

While biomass for electricity generation holds great potential, there appears to be ample feedstock in industrial plantation operations. Short rotation eucalypt production may have some potential in agroforestry, especially if integrated tree processing plants (such as the Narrogin plant) are developed. However this would require significant investment, which in turn requires policy stability around renewable energy.

2.6 Bio-Oil production

To date, although the potential for industrial scale production of bio-oils is high there has been little uptake in Australia. Much of this has been because the costs of production have been considered too high to be economically feasible, especially when compared to the cost of petroleum based oil products although, pilot plants are now proving the technology (http://www.licella.com.au/the-wonder-from-down-under-licella-pulp-joint-venture-is-lead-story-in-the-digest/, viewed 12/06/2017). However this may not necessarily limit the development of plantations as farmers may not be averse to new farming activities despite a lack of an existing

market or infrastructure for farm grown woody biomass (Farquharson *et al.*, 2013). As with biomass described above the highest potential appears to be associated with co-generation, i.e. the use of waste streams for a range of end products, e.g. ethanol, biodiesel and activated charcoal. There has been considerable work done on mallee systems as feedstocks for this industry and the potential remains high. While the technology is proven, scalability will depend on a range of market forces. Reliability of feedstock supply is critical, however this is unlikely to eventuate in the absence of processing plants, especially within a reasonable transport radius from a such a facility, resulting in a circular constraint on investment (Fritsch & Hudson, 2008). Mendham *et al.* (2015) conducted an evaluation of cineole production from farm forestry in Western Australia. They explored two case studies, a larger scale jet fuel production case study and a smaller scale biomass-fuelled heat and power plant for an abattoir. In both case studies the estimated cost of cineole production was below world prices and there was significant potential to scale up production. However they also noted that the mallee industry was still prospective and that further work was needed for the industry to realise its potential.

2.7 Essential Oils

The global essential oil market exceeded six billon $US in 2016, driven by growing consumer preference for natural products and rising market demand, particularly in developing countries such as China, India, Vietnam and Thailand. Oils service a range of markets including medical, food and beverage, spa and relaxation and cleaning. Entry barriers appear to be high as the market is dominated by vertically integrated international companies (source: http://www.grandviewresearch.com/industry-analysis/essential-oils-market, viewed 12/06/2107).

In Australia essential oil production is from both native plants such as *Eucalyptus* spp., lemon myrtle and tea tree (*Melaleuca alternifolia*) as well as from introduced species such as peppermint, fennel and lavender (Chudleigh *et al.*, 2013). Global production (75%) of eucalypt oil is dominated by *Eucalyptus globulus*, produced mainly in China, Portugal and India (Hobbs *et al.*, 2006).

Bush *et al.* (2016b) reviewed options for dryland forestry in Australia and found that there was potential for the expansion of Southern Sandalwood (*Santalum spicatum*) forestry in Australia. Southern Sandalwood is a root hemiparasite that occurs naturally in range of semi-arid vegetation types that produces valuable aromatic oils within it heartwood (Brand, 2009). In southern Australia, *Santalum spicatum* is well adapted to growing on low rainfall sites in the wheatbelt of Western Australia. There is growing global demand for sandalwood, and in 2015 *S. spicatum* was trading for $16,000 per metric tonne for good quality uncleaned logs (Bush *et al.*, 2016a).There have been a number of trials in Western Australia with this species to reduce reliance on wild harvests, however there have been no published trials in eastern Australia, despite the RIRDC website (farmdiversity.com.au) highlighting that environments in eastern Tasmania and Victoria may be climatically suitable (Figure 2), and that there is potential for development of sandalwood windbreaks and shelter belts.

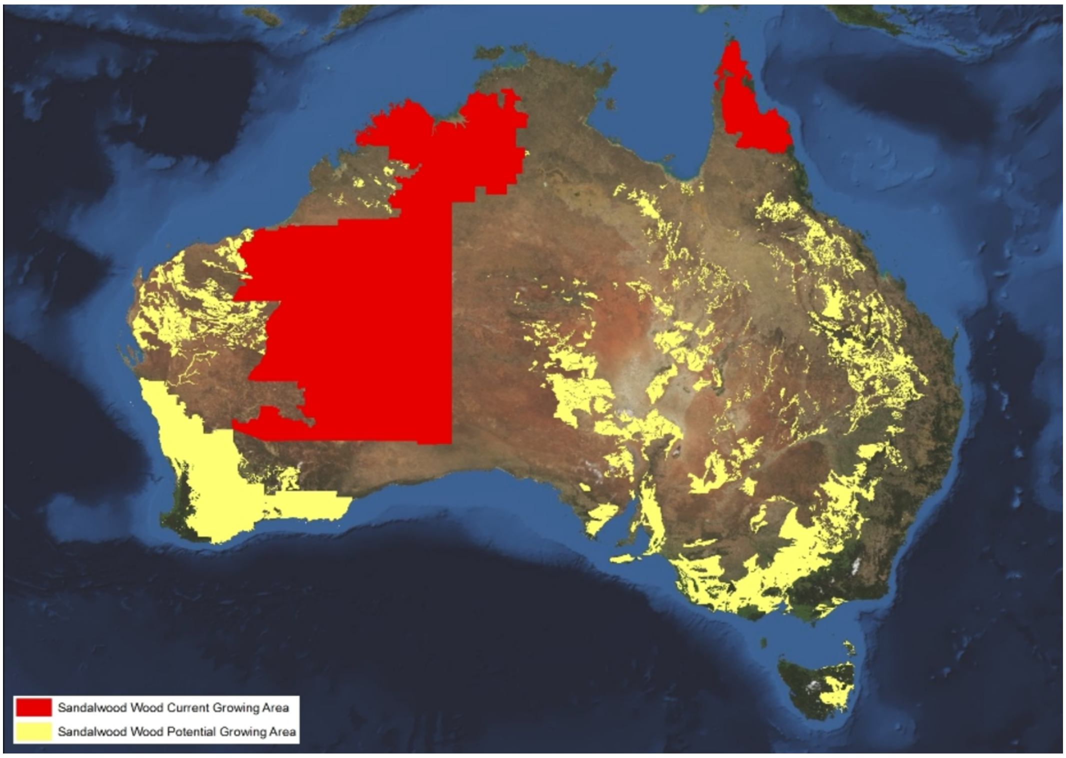

Figure 2 Climatic suitability of sandalwood (*Santalum spictum*) in Australia (source: farmdiversity.com.au)

3 Complementarity benefits

Chapter Summary

- Shelterbelt benefits for crops are most significant during relatively extreme weather. conditions: high wind, extremes in temperature and may offer large benefits on highly erodible soils.
- Solid evidence to support higher lamb survival when tree shelter is available.
- There are benefits to other livestock productivity indicators such as, wool and weight gain, however the evidence is less unanimous.
- For shelterbelts to be effective, wind velocities need to be reduced by at least 50% under most conditions.
- Amenity values represent at least 4% of land value but can vary according to the extent, scale and surrounding market conditions within the district.

3.1 Trees as shelter

One of the most comprehensive research projects undertaken in Australia on responses agricultural systems to windbreaks was the 'National Windbreaks Program - summarised by Cleugh *et al.* (2002). Tree belts provide shelter effects on the leeward side of the belt and the influence of the trees can be summarised into three zones relative to tree height (H): 'competition zone' (-2H to +2H) – where competition for resources with crops is high, 'quiet zone'(2 – 8H) – where large declines in wind velocity increase temperature and/or humidity and lower soil evaporation, 'wake zone'(>8H) – where changes in temperature and humidity are small but reduction in wind velocity can help avoid soil erosion and crop damage (Figure 3). From the schematic below, the height of the windbreak determines the distance over which wind is reduced and the relative positioning of the zones described above independent of the windbreak porosity (Cleugh & Hughes, 2002, Wang & Takle, 1997). However, porosity will determine the magnitude of the decrease in wind velocity achieved by the windbreak (Cleugh & Hughes, 2002).

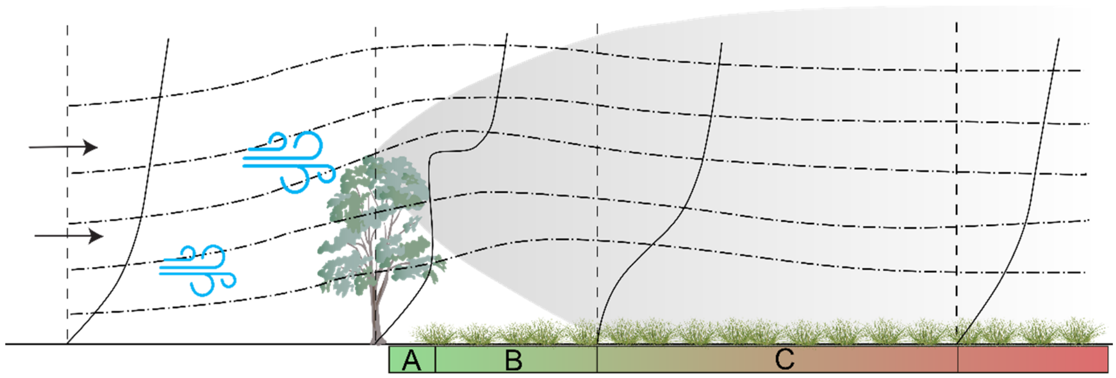

Figure 3 Airflow zones perpendicular to a porous windbreak. A) Competition zone, B) quiet zone and C) wake zone (see text for details; modified from Cleugh and Hughes, 2002). Solid lines (perpendicular to the land surface) represent wind velocity profiles across different zones.

3.1.1 Shelter impacts on crop yields

The National Windbreaks Program found reduced yield gains from windbreaks than what was expected based on previous global studies, especially for cereals (Cleugh *et al.*, 2002). Economic analysis accounting for net costs and gains showed only small financial gains or cost neutral among the sites in southern Australia used in the bioeconomic analyses of Carberry *et al.* (2002). This research and the few more recent studies (Bennell & Verbyla, 2008, Oliver *et al.*, 2005) maintain that the small and relatively variable effects on crop yield can be explained in part by the variable nature of wind conditions and suggests that the benefit of a single tree belt is only realised during certain times.

Monitoring of yield in shelterbelts at 32 sites in the period 1997 to 2000, found responses in the zones where yield was unaffected by competition averaged 3.7% for cereals (over a distance of 2.2 to 9.7 tree heights) to 14% for pulses (over a distance of 1.7 to 10.4 tree heights) (Bennell & Verbyla, 2008). Shelterbelts are likely to offer some of the largest benefits in soils that are erosion prone and where crops of pulses are grown (Nuberg & Bennell, 2009). Under other circumstances much of the literature suggests that windbreaks appear to play a key role in protection from infrequent high magnitude wind events that cause plant and soil damage, such that the most significant benefits of windbreaks are realised during dry, hot and/or windy conditions.

3.1.2 Shelter impacts on livestock

Tree belts may provide considerable benefits in reducing stress on livestock associated with extreme conditions. Profitability of livestock is increased if shelter from tree belts can help avoid mortality and large energetic costs of exposure to cold. For example, Bird *et al.* (1984) showed a 50% reduction in lamb mortality during extreme cold conditions where shelter was provided by trees. Tree belts can act as ‘maternity wards’ because they can increase survival rates especially in twin lambs (Robertson *et al.*, 2011). Although the effects of shelterbelts on lamb survival is context specific, the largest positive effects are observed when lambing coincides with cold, wet and windy conditions (Broster *et al.*, 2012). Young *et al.* (2014) conducted bio-economic modelling of farm profitability in sheep grazing systems and showed that the reduction in lamb mortality brought about through using perennial grasses (tall wheat grass) as shelter was the main driver of increased economic returns to the grazing enterprise. While there is limited experimental tree-

livestock studies since the 1980's the available research suggests that for shelterbelts to be effective, a reduction in wind speed of >50-75% is necessary (Broster *et al.*, 2012) with correct orientation to prevailing wind at lambing time (McCaskill & Clark, 2007).

The impacts of tree belts on weight gain, milk or wool production is difficult to discern given the limited number of quantitative studies using trees to as shelter (see Baker *et al. under review*). Experimental studies exploring the effect of shelter, based on using artificial materials or trees, has shown reductions in cold stress and gains in both weight and wool production. Recent evidence based on tracking the movement of sheep using GPS tags clearly demonstrated that sheep frequently utilised tree shelter during cold conditions (Taylor *et al.*, 2011). When sheep stocking rates were increased, artificial shelterbelts were found to increase wool production by 30% and live weight gain by 20% in the temperate climate of Armidale, (Lynch & Donnelly, 1980). This was similar to a study involving shorn sheep where wind breaks causing a 50% reduction on wind speed increased live weight gain by 30% (Anderson, 1986). Shelterbelts in New Zealand have been shown to increase butterfat content of milk by 5%, in contrast to areas deprived of shelter lead to a decrease of 11% in milk butterfat content (Hassall, 2008)..

Heat stress can also be reduced through shading and shelter from hot, dry winds typical of heat waves in southern Australia. Heat stress affects wool growth through reducing feed intake (Anderson, 1986). For dairy systems, shade provided to cows in pre-milking yards can increase milk yield (11.44 *versus* 10.95 kg per milking cow for shade and no-shade respectively) and improve overall cow comfort (Wildridge *et al.*, 2017). Hence, the benefits of tree belts in strategic positions within the livestock enterprise may reduce heat stress, not just at grazing sites but in other sensitive areas. Given the observed and projected upward trajectory of global temperatures (Steffen *et al.*, 2017), and the increasing emphasis on animal welfare by consumers, amelioration of heat stress may become an increasingly important aspect of agricultural adaptation and help to sustain farm productivity.

3.2 Farm amenity

Lifestyle and amenity values of farm forestry are often recognised as significant motivators for farm forestry (Hassall, 2008). A number of attempts have been made to assess the impacts of farm forestry on land values. Hassall (2008) report a study by Field et al 2006 (pg 36) that found a significant correlation between tree cover and land value. Specifically 5-50% tree cover can result in a 25% increase in property values relative to a similar cleared property. Attribution of farm forestry is difficult and requires careful analysis, as often there are significant gaps in the knowledge about farm forestry activities (Schirmer 2005). EBONS (2015) reported that land values associated with farm forestry were up to 15% higher.

In contrast, Reynolds and Sinden (1979) conducted an empirical analysis of the costs associated with avoided land clearing to protect amenity value finding that environmental policy to restrict land clearing could lower property values reporting that every 1 m^2 increase in basal area could drive property values down by \$3.40 ha^{-1}. In this study however, the amenity value was considered an externality, i.e. the value was attributed to the broader community rather than the farm itself, and attitudes to trees could well have changed in the interim.

In probably the most extensive peer reviewed analysis to date, Polyakov et al., (2015) analysed 7200 property sales since 1992 found that the marginal benefits of retaining native vegetation of farms was greater for smaller (1 ha) and medium sized farms than on larger properties (~1000 ha), noting that in the case study (north central Victoria) area the current extent of native vegetation is lower than the extent that would maximise the amenity values to a many landowners (land value highest when 20% native vegetation, returned a 4% premium).

4 Weighing up the environmental benefits of agroforestry

Summary

- The environmental benefits of trees are realised in many different forms of agroforestry systems from industrial plantations through to ecological restoration.
- Management of excess recharge and salt land has relied on targeted species-site selection and it can be very effective, though efficacy depends on underlying catchment hydrogeology.
- Agroforestry offers significant benefits for the retention and management of soil and excess nutrients, particularly in riparian areas and drainage channels. Information on the design and management of tree belts to achieve these objectives are reasonably well defined.
- The extent to which agroforestry fosters biodiversity and native habitat depends on the system and its ecological setting. Agroforestry is likely to provide additional habitat for many species compared to adjacent agricultural landscapes.
- Biodiversity can be enriched by considering: site-level factors - characterised by complexity, composition and ecological management, and, landscape-level factors, which in turn are characterised by location and configuration.
- While little is known about the role of native pollinators in Australian agriculture, growing concerns around biosecurity threats and meeting growing demand for pollination services suggests an increasing need to increase pollinator habitat resources through agroforestry.

Agroforestry systems span a range of primary objectives with different management requirements (Figure 4) that are likely to deliver differing environmental benefits and services within the agricultural landscape (Lin *et al.*, 2013). In most cases the value placed on the system is based on single benefits flowing from a particular agroforestry activity (eg. production of wood, or sequestration of carbon). In reality agroforestry systems provide multiple benefits, disbenefits and services that need to be captured to evaluate the net benefit of any activity. Here, we detail four key areas of potential environmental benefits provided by trees in the agricultural landscape.

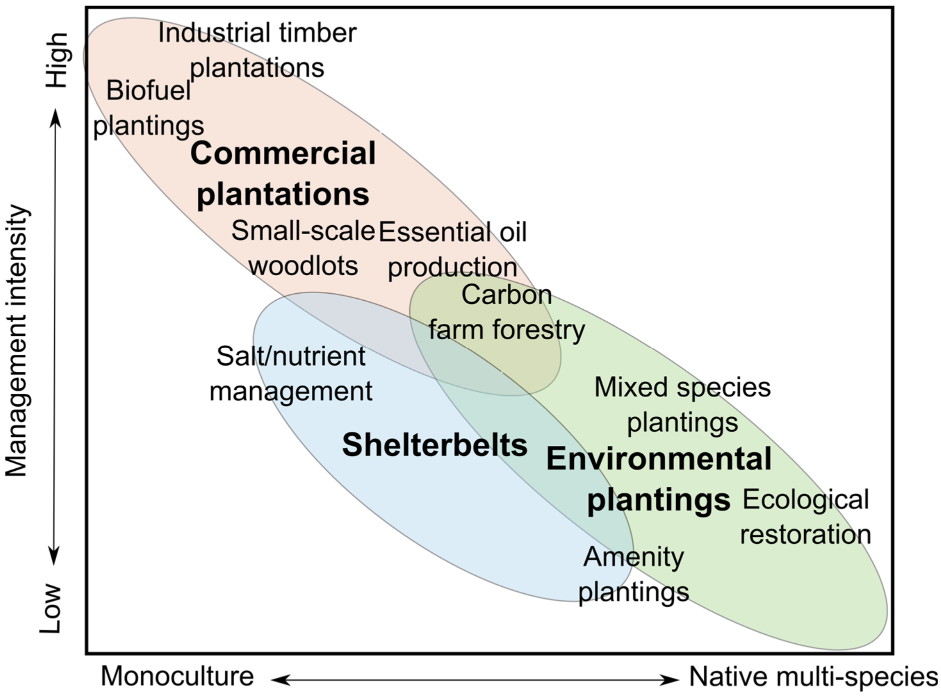

Figure 4 The range in agroforestry systems is based on the primary purpose of the planting and can include plantations for timber or biofuel products, tree belts for shelter, multi-species or biodiversity plantings and remnant vegetation restoration. Management intensity is related to the objective of the planting.

4.1 Water management

There are several interrelated features of tree farming systems that affect farm and catchment scale hydrology. The most significant impact on landscape water balance from agroforestry is an increase in annual evapotranspiration across the landscape. This occurs because trees normally exploit a larger fraction of the soil volume and available soil water, through an extensive root system, than agricultural pastures and crops (Greenwood *et al.*, 1985, Zhang *et al.*, 2001). Consideration of these fundamental differences in plant water use, prompted the widespread adoption of tree- and other perennial crop-based methods in Australia to reduce excess recharge in response to growing land degradation from dryland salinity (Stirzaker *et al.*, 1999). Applied research into tackling dryland salinity has helped to advance our knowledge of landscape hydrology in mixed farming systems and the extent to which broader patterns in water cycling might be managed or improved e.g. landscape-scale (Brooksbank *et al.*, 2011, McJannet *et al.*, 2000) and catchment-scale (Beverly *et al.*, 2005, George *et al.*, 1999).

The Denmark catchment in south-west of Western Australia is one of the first catchments in Australia to recover from dryland salinity. A large driver of this success was the expansion of plantations in the 1990's to 2000's and the conservation of native remnants (Ward *et al.*, 2011). These activities formed part of an integrated catchment management plan that saw afforestation of up to 50% of the previously cleared areas in the upper catchment, areas that were suitable for blue gum plantations (Ruprecht, 2004). During the 2000's, the Commercial Environmental Forestry program of CSIRO and the Department of Agriculture, Forestry and Fisheries was established and focussed on many aspects of the on-farm and off-farm benefits of trees. The program developed a Scenario Planning and Investment Framework to assess the most effective parts of the catchment that could be planted with plantation forests. The analysis in the Goulburn

Catchment in south-eastern Australia, highlighted the importance of targeted expansion of new plantations (Booth, 2012). For example, it was predicted that 50% of the maximum achievable effect, in terms of reductions in stream salinity, could be realised if only 2.5 % of the total catchment or 20% of the identified 'target' areas were planted to radiata pine (van Dijk *et al.*, 2004). These 'target' areas were selected based on being suitable for production (> 15 m^3 ha^{-1}) and were expected to have only minor negative impacts on catchment water yield (van Dijk *et al.*, 2004). In other areas such as the dryland cropping belt of Western Australia, a much larger area of trees in the catchment (as much as 70-80%) would be required to bring about reductions in groundwater recharge (George *et al.*, 1999). Clearly, these studies have evaluated plantation impacts in very different catchments, where hydrogeology, soil, climate are different, thus limiting the generality of such findings.

Utilising unproductive salt land or localised discharge areas for forestry can help manage local hydrology, while providing potential farm forestry resources (Boxshall & Mitchell, 2008). Strong interest in saltland forestry in 1990's and 2000's produced a solid body of work on: species salt tolerance, site selection and preparation and improved genetic resources (Patabendige *et al.,* van der Moezel *et al.*, 1989). As documented in Table 5, this research has been distilled into useful guides for landholders to assist in matching tree species and site conditions (Marcar *et al.*, 1995).

In higher rainfall areas, there are concerns surrounding the negative impacts of afforestation on catchment water balance. These impacts have been studied primarily in both native forests and plantations and are predicated on the observed trend towards lower streamflow for a given annual rainfall in forested catchments *versus* catchments primarily vegetated with herbaceous plants (Zhang *et al.*, 2001). The changes in streamflow associated with re-establishment after clearfalling of wet, eucalypt-dominated native forests in south-eastern Australia can include an extended period (sometimes >100 y) where stream flow remains lower than pre-disturbance conditions, indicating large increases in canopy transpiration in young, fast growing stands of *Eucalyptus regnans* and other co-occurring species (Langford, 1976, Vertessy *et al.*, 2001). Industrial plantations have long been recognised as a potential risk to water yields, especially in countries such as South Africa, where plantations of eucalypts and other exotics has caused declines in water supply (Dye & Versfeld, 2007). In Australia, the extent of plantations across suitable growing regions has not affected water yields as drastically as other countries, presumably because of their smaller scale and intensity (Benyon & Polglase, 2009). Benyon and Polglase (2009) noted that local impacts within catchments can be significant where plantation areas are extensive, but at the catchment and regional scale, impacts of farm dams, bores and climate change were seen as larger factors influencing water yield. Given the likely scale of most farm forestry ventures that integrate multiple production systems into the landscape, and the large increases in forest cover required to detect significant changes in streamflow (>20%), such changes are unlikely to be found in farm forestry situations (Brown *et al.*, 2005). Hence, the potential multiple on-farm and off-farm benefits are most likely to dominate over any sustained changes in catchment water yield in higher rainfall agroforestry systems (>800 mm).

4.2 Soil and nutrient management

The benefits of tree farms and agroforestry on water quality, nutrient and sediment runoff and soil erosion is a major driver for adoption worldwide (Nair *et al.*, 1995). There is evidence in farming systems globally that agroforestry can reduce runoff and nutrient yields (Schmitt *et al.*, 1999, Udawatta *et al.*, 2002). At the catchment scale, Viney and Sivapalan (2001) used catchment modelling to estimate the magnitude of revegetation required to bring about significant reductions in nutrient loads into surrounding estuaries in south-western Australia. Their results showed that a relatively small area of targeted reafforestation of radiata pine resulted in proportionally larger reductions in nitrogen and phosphorous yield from sediment loads than larger areas located in non-target positions (Viney & Sivapalan, 2001). The study of Zammit *et al.* (2005) also concluded that reafforestation has larger proportional impacts on N export than P export because of the large stores of inorganic P that continued to leach through the catchment.

Targeting farm forestry in areas that can intercept and draw down excess nutrients can help reduce net export of nutrients from the farm while providing suitable tree species with favourable growing conditions through increases in water and nutrient availability (Bennett *et al.*, 2015). The use of streamside buffers can be a highly effective target for farm forestry activities. Tree uptake of subsurface runoff and shallow groundwater in relatively narrow (~10m wide) riparian zone can remove significant levels of nitrate and buffer the impacts of fertiliser application in adjacent land (Rassam *et al.*, 2008). In a paired catchment study in southern Tasmania, the fencing of streamside vegetation that included *E. nitens* plantations, reduced the concentrations of phosphorous, sediment and bacteria during significant rainfall events (Smethurst *et al.*, 2010). This can also have additional benefits for landscape function and biodiversity if farm forestry stands can reduce nutrient transport to native remnants sensitive to additional N and P inputs (Duncan *et al.*, 2008). Other examples of managing nutrient-rich wastes that may be relevant for agricultural systems include irrigation of plantation species with treated effluent from municipal waste streams (Myers *et al.*, 1996). However, the efficacy of using tree stands to reduce excess nutrients from effluent is dependent on site factors such as soil type, effluent chemistry and tree age and stand development (Smith *et al.*, 1999, Myers *et al.*, 1999).

Agroforestry systems also have the potential to improve soil health and nutrient levels through the accumulation of organic matter in the soil and the use of nitrogen-fixing species (Jose, 2009). Even in scattered trees in grazing systems, tree litter fall can provide a significant input of soil nutrients that can extend beyond the tree canopy (Barnes et al., 2011). In grazing systems, low nutrient soils tend to have largest increases in nutrient availability under native eucalypt canopies, having positive impacts on forage quality and productivity in native grasses (Jackson & Ash, 2001). Agroforestry systems using radiata pine in New Zealand have had positive influences on surface soil nutrient levels (higher phosphorous, magnesium, sulphur and potassium) (Hawke & O'Connor, 1993). The carbon and nitrogen fraction in soil particulate organic matter tended to increase under *E. globulus* plantations and was accompanied by a 50% decline in N mineralisation (Mendham et al., 2004).

At the paddock scale, the capacity for interception of sediment and nutrients by vegetation decreases as water flows downhill toward the stream network (Hairsine & van Dijk, 2006). The amount of interception from an upslope area by tree belts or blocks depends on local rainfall characteristics, landscape form (such as the density of drainage lines and gullies), slope, and soil

surface roughness and infiltration capacity above and inside the planting (Hairsine & van Dijk, 2006). Several factors need to be considered when planning the location and extent of the tree plots to minimise erosion at the paddock and whole of farm scale (Hairsine & van Dijk, 2006). It is recommended that tree lots should be oriented cross slope, with ripping and mounding practices targeted toward reducing overland flows and sediment transport (Hairsine & van Dijk, 2006). Experimental studies show that 5 m belt widths can capture much of the sheet and rill surface flow (Ellis *et al.*, 2006). Once established, maintaining ground cover, via understorey and litter accumulation is critical for reducing sheet, rill erosion and tunnelling (Hairsine & van Dijk, 2006). This is often initiated and maintained by removing stock.

Targeting revegetation around drainage networks, such as roads and riparian areas can be very beneficial in reducing erosion. Stream bank erosion is common where riparian vegetation is degraded or removed and farm forestry systems can be used to minimise flow velocity of high intensity rainfall events (Hairsine & van Dijk, 2006, Huang & Nanson, 1997). Evidence for this was found in the Goulburn Catchment where afforestation in and around drainage channels helped to stabilise stream banks (Hairsine & van Dijk, 2006).

4.3 Biodiversity and habitat protection

Biodiversity is an emergent system property arising from the composition, function and configuration of tree stands at a range of scales. At the farm-level biodiversity usually refers to the suite of indigenous species that occur and interact at that site. Trees in the landscape provide added structural complexity, habitats and food sources for non-agricultural species within the farming landscape. These ecosystem services can potentially bolster local and regional biodiversity and have consequences for farm resilience to pests and diseases (Dames & Moore NRM & FORTECH, 1999). Given the broad set of motivations and planting types that might be implemented on the farm, realised biodiversity outcomes often intersect several other commercial and environmental interests. While there are obvious trade-offs between commercial and biodiversity objectives for farm forestry, there is considerable research on how best to maximise the biodiversity outcomes through careful management and the potential for sound public policy to foster greater involvement and action.

Improving biodiversity at the design stage of farm forestry ventures includes a range of strategies with demonstrated effectiveness (Dames & Moore NRM & FORTECH, 1999) such as:

- Incorporating patchiness in species and age classes.
- Planting of indigenous or habitat species on less productive areas within and around farm forests.
- Use of buffer plantings.
- Use of nurse crops in farm forests.
- Dispersal of slash rather than burning.

The spatial layout and configuration of tree stands, such as proximity to remnant vegetation, appears to be an important factor in the extent to which agroforestry can improve habitat resources on the farm (Thomson *et al.*, 2009). For example, studies in industrial plantations show

the provision of additional habitat is beneficial for a number of species compared to agricultural and pastoral land (Baral *et al.*, 2013, Lindenmayer & Hobbs, 2004). Habitat provision for birds has been observed in exotic plantations (*Pinus radiata*) where half of the species found in mature native forest were observed in the pine plantations (Suckling *et al.*, 1976). Patterns of biodiversity values in eucalypt plantations show that they generally fall between that of agricultural land (lowest) and native eucalypt vegetation (highest) (Grimbacher, 2011). Many of the biodiversity outcomes identified in industrial plantations apply to farm forestry and in many cases the benefits may be greater where trees are replacing land under grazing or cropping regimes. Biodiversity can also bring challenges to farming systems, if the forested land is acting as a shelter for browsing mammals or other pests, which may need to be addressed through the use of game-proof fencing.

Strategies to improve landscape connectivity and provide different structure and habitat resources (Vesk & Mac Nally, 2006) on a catchment or regional scale can offer significant benefits. In Australia there are several large, regional-scale revegetation initiatives, such as Gondwana Link (http://www.gondwanalink.org/), the Midlands Restoration Program (https://www.greeningaustralia.org.au/project/Island-Ark-program) and Habitat 141 in Victoria (https://www.greeningaustralia.org.au/project/habitat-141), that are harnessing restoration and farm forestry activities to improve connectivity and habitat availability. For example, the Tasmanian Midlands Restoration Program involves targeted revegetation across a fragmented farming landscape in central Tasmania with the aim of reinstating wildlife corridors between the western areas of the state (including world heritage areas) and the eastern region (Bailey, 2013b). This includes riparian and upslope plantings of local and climate-ready provenances of native species (Harrison *et al.*, 2017). Many of the opportunities for biodiversity enhancement include the utilisation of non-commercial areas around plantation estates. These areas include remnant vegetation, streamsides, firebreaks, setbacks from utilities and roads and steep or unproductive sites, which can also have landscape connectivity with adjacent natural areas (Stewart et al. 2006) (Archibald *et al.*, 2011).

The potential for perverse outcomes on biodiversity from inappropriate plantings can arise when they are not planned appropriately (Lindenmayer *et al.*, 2012). This is often discussed in light of carbon plantings in terms of: the spread of invasive species, major disturbance such as wildfire, impacts on water resources and failure to factor in ecological uncertainty over the life of the project (Bradshaw *et al.*, 2013, Lindenmayer *et al.*, 2012). The potential for reafforestation to increase the abundance of vertebrate pests such as foxes, cats and rabbits may also occur under some circumstances (Catling & Burt, 1995). Currently, the Carbon Farming Initiative does not explicitly integrate improvements in biodiversity into its methodologies, but attempts to avoid any further damage to biodiversity values (van Oosterzee, 2012). Previous public policy such as the now defunct Biodiversity Fund, represented an attempt to mitigate some of these ecological risks by bundling biodiversity outcomes with carbon markets. The aim of the policy was to maximise biodiversity benefits by providing direct payments for carbon sequestration projects that also deliver biodiversity benefits (Stephens & Grist, 2014). However, this policy was criticised for its lack of clear ecological objectives and limited investment in monitoring the success of the plantings over the life of the initiative. Thus, embedding biodiversity principles within agroforestry activities need to be explicitly planned and monitored if they are to be realised and perverse outcomes avoided.

Several methods for assessing biodiversity values of on-farm plantings have been proposed based around design themes and the principles of the management program. One of the most recent approaches to date was the 'Plantation Biodiversity Index' devised by Freundenberger and Cawsey (2005) based on the ecological design framework and comprehensive guidelines set out in Salt *et al.* (2004). It builds on previous biodiversity assessment approaches that operated at the site-scale such as 'Habitat Hectares' (Parkes *et al.*, 2003) and landscape-level approaches (Ferwerda, 2003). The 'Plantation Biodiversity Index' scorecard covers both of these scales and represents a qualitative method to gauge the biodiversity benefit obtained from a farm forestry activity (Freundenberger & Cawsey, 2005).

The site-scale components of the index broadly sit within three themes related to:

- Complexity - structure, rotation times and patchiness.
- Composition - species and genotype.
- Ecological management - weed and pest control.

Landscape-scale components include:

- Location - connectivity and landscape position.
- Configuration - size and shape.

4.4 Pollination services

Pollination plays an extremely important role in underpinning global food security, with about 75% of the world's major crop species, representing 35% of world crop production, reliant on pollination (Boreux *et al.*, 2013). Given the importance of pollination, there is growing global concern over well-documented declines in pollinator diversity, which is thought to be associated with a range of threats including changes in land use management, climate change, pesticides and genetically modified crops, and invasive species. In a global review on the contribution of wild pollinators to fruit set, Garibaldi *et al.* (2013) found that wild pollinators significantly increase pollination efficiency, increasing fruit set by twice that facilitated by honeybees. Potts *et al.* (2016) reviewed the threats and regional trends in pollinator diversity, finding that a key strategy for mitigating against future pollinator declines include strengthening diversified farming systems through a range of measures including the adoption of agroforestry systems.

In Australia, 35 industries are dependent on pollination (largely by honeybees) and this pollination service was valued at $1.7 billion per annum in 1999-2000. While in Australia there is significant flow of pollination services from incidental pollination associated with feral bees and other native pollinators there is insufficient research to understand weather this "free" pollination service is sufficient to meet the full potential of the crops being considered. Furthermore, pollination services in Australia are facing significant risks including:

- Varroa mite and other bee diseases and pathogens.
- Chemical threats.
- Integrated pest management (IPM vectors may prey on honey bees).

- Rising honey prices may reduce the number of hives available for pollination (Keogh *et al.*, 2010).

Research into the design of pollinator landscapes in Australia is generally at an early stage. Much of the research based in Europe or the United States and reflects the rising concern over the decline in important pollinators. However, agroforestry has been shown to be an important management intervention to improve pollinator diversity. Scheper *et al.* (2013) found that agroforestry increased landscape complexity, measured as the proportion of semi-natural habitat. The impacts were largest in highly modified landscapes, i.e. the introduction of shelter belts into relatively homogenous agricultural landscapes not only improved the diversity of foraging habitat, but the increased structural complexity, increasing the availability of roosting sites. Varah *et al.* (2013) studied a range of agroforestry systems in the UK, finding that pollinator diversity significantly increased in all systems relative to the control paddocks (without agroforestry). However, there were interactions with land use, arable systems had a significant increase in pollinator species richness, however this was not the case in pastoral systems, presumably because of the higher plant diversity in this system. Kaiser-Bunbury *et al.* (2017) examined 64 plant pollinator networks across four restored and unrestored communities. Ecosystem restoration resulted in a marked increase in pollinator species, visits to flowers and interaction diversity. They noted that interactions in restored landscapes were more generalised than in unrestored landscapes, suggesting a higher functional redundancy in restored communities. Kormann *et al.* (2016) also found that vegetation corridors boosted forest associated pollinators in fragments by 14.3 times, although in that study they were mainly interested in vertebrate mediated pollination of tropical forests rather than pollination of agricultural crops.

In Australia, research into the impacts of agroforestry on pollination services is minimal. However, remnant vegetation provides an important reserve of nectar and pollen resources. Many of the commercial horticultural crops do not provide good quality pollen or nectar resources, thus apiarists servicing the pollination industry require access to good quality foraging provided by native forests and remnant vegetation (Keogh *et al.*, 2010). Furthermore Dicks *et al.* (2016) highlight that ecological intensification practices in agricultural landscape could significantly contribute to securing pollination services, recommending the use of flowering hedgerows, increased habitat patchiness and intercropping, to increase the diversity of pollen and nectar sources. Maintaining habitat for nesting was also important, including retaining coarse wood timber and hollows. Eby (2015) highlighted the potential of current environmental planting projects to provide benefits for large nomadic vertebrate pollinators. They identified a bottleneck in floral resources during winter and spring that could be addressed through specifically selecting plants that provide nectar and pollen resources during this period for inclusion in environmental plantings to help promote pollinator conservation. Menz *et al.* (2011) highlights that the challenges of restoring pollination services in landscapes needs greater co-ordination between plant restoration ecologists and pollination ecologists. They propose that revegetation include a mixture of "framework" plant species and "bridging" plant species. Framework plants are those that provide nectar and pollen resources to a range of pollinator species, whereas bridging species provide pollen and nectar resources during otherwise resource limited times. It is important that the selected framework plants are not so nectar rich that they outcompete the agricultural crops for pollination services. They conclude that to support pollinator colonization and persistence in

agricultural regions requires that the requirements of the pollinators are met entirely within the restoration plantings or within foraging distance of the restoration site.

5 Capturing the value of agroforestry through natural capital: internalising the externalities

Summary

- Decision support tools range in applicability from broad-brush species selection/scoping tools to detailed forestry growth modelling tools. However, they are very limited when it comes to assessing benefit cost of direct and indirect commercial components.
- Natural capital accounting is a potential mechanism for internalising the externalities arising from the suite of ecological services from agroforestry
- Integrated reporting of the financial and natural capital within the farm balance sheet offers a potential pathway to demonstrate the benefits of agroforestry in a way that has not been previously employed, though this thinking remains in its infancy.
- We offer a preliminary assessment of how different agroforestry systems may provide different sets of regulating and provisioning services for the farm enterprise and the relevant indicators to measure their effectiveness.

5.1 Decision support tools for evaluating agroforestry projects

The availability of decision support tools to landowners, managers or policy-makers is somewhat limited, especially for assessing the influence or potential cost/benefit of the combination of various products and environmental services that may flow from various agroforestry systems. The table below lists some relevant support tools that are available for assessing different outcomes and benefits from the; tree system, the competition/complementarity interactions between tree and agricultural enterprise and ecosystem services at the farm and landscape scale (Table 6). In all decision-support tools the value from ecological services of the agroforestry system has not been quantified. As discussed in section 4.3, most approaches to evaluate environmental benefits are highly context-specific and use qualitative methods such as score sheets, in order to prescribe value from a particular forestry activity.

5.1.1 Assessing tree-based products and site selection

Broad brush planning tools help to inform suitable species selection based on suitable growing conditions and/or target markets and management/infrastructure requirements. The Atlas of Living Australia (http://www.ala.org.au/) can be used as a species selection tool for generating bio-climatic profiles of a potential target species based on observations of plants in their natural and managed locations (Booth *et al.*, 2012) (Table 6). This may be particularly useful for tracking current and future climate conditions for a particular species distribution to inform the suitability of species for permanent plantings for carbon and/or ecological restoration (Booth *et al.*, 2012). However, this approach ignores the ability of many forest tree species to grow successfully well outside their natural temperature and rainfall distributions (e.g. *Eucalyptus globulus*). The climate envelope approach is also used in the 'Farm Diversity' tool (http://www.farmdiversity.com.au/), a

web-based, species selection tool providing a starting point for species selection of potential high-value species suitable to a particular location (Table 6). The advantage of this tool is that is lists production, infrastructure and processing/harvesting requirements as well as important market information.

Tools such as 'Farm Forestry Toolbox' provide established methods to design and monitor on farm wood resources, carbon accounting and some high-value products such as oil mallee and sandalwood. The tool is specifically designed for the landholder or forestry manager and is based on a suite of forest growth and economic models, as well as relevant health and diagnostic tools (Table 6). Currently, the CFI requires monitoring and the use of the government's reforestation tools (http://www.environment.gov.au/climate-change/emissions-reduction-fund/cfi/reforestation-tools) to calculate estimates of greenhouse gas emissions and removal for particular tree stands referred to as Carbon Estimation Areas (Table 6). The Reforestation Modelling Tool provides proponents with an interface to enter information about site details including: location, size, configuration, composition/planting type, silvicultural details and disturbances. This is a somewhat simplified empirical forest growth calculator and is probably is best suited as an accompanying tool to a more rigorous and flexible tool like the Farm Forestry Toolbox.

5.1.2 Complementarity values

Given the system and site-specific nature of observed costs and benefits of agroforestry on the whole of farm enterprise, tools in this category that implement bio-economic modelling can be relatively challenging for non-specialists. Assessing the benefits of trees for shelter is difficult given the lack of experimental evidence and reliance on extensive assumptions, however the 'Shelter for Lambing Tool' from the EverGraze program provide a relatively simple tool for identifying benefits from shelter belts for lamb survival (using perennial grasses or shrubs, Table 6). This tool implements the MIDAS farm modelling tool (Kingwell & Pannell, 1987) to produce net farm income scenarios for a range of farm climatic, agronomic and shelter combinations (Table 6).

5.1.3 Optimising multiple production and environmental benefits

Several approaches and management tools have emerged that attempt to integrate the co-benefits from carbon forestry. Summers *et al.* (2015) developed the Landscape Futures Analysis Tool, which is a regional-scale analysis tool for identifying and evaluating areas where the co-benefits of carbon farming, biodiversity and salinity management intersect with appropriate opportunity costs associated with displacing farming land. The Landscape Futures Analysis Tool is relevant for initial scoping and assessment for land managers and landholders who want to gauge the potential of areas where optimal production and environmental benefits can be realised. Presently, the tool only reports on two regions in South Australia (Eyre Peninsula and SA Murray Darling Basin) (Table 6).

Table 6 Decision support tools for the planning, design and monitoring of agroforestry systems in southern Australia.

SYSTEMS SCALE	TOOL NAME	YEAR LAUNCHED	DELIVERY APPROACH	BENEFITS/OUTCOMES DOMAIN	UNDERLYING MODEL FRAMEWORKS	TARGET AUDIENCE	USER INTERFACE	OUTPUT	REFS AND DETAILS
Continental (Australia)	Atlas of Living Australia	2012	Website - desktop	Biodiversity and environmental plantings and species selection/assessment	Essentially a 'living' database of known species distributions. Additional data on climate	Researchers, landholders, managers	Mapping portal with additional analysis and modelling tools	Species locations observed (includes natural and managed occurrences)	http://www.ala.org.au/
Farm scale	Farm Diversity	2014	Website - desktop	Diversify farm enterprise using existing and emerging industries	Distribution models of potential and current occurrence (covers managed and natural distributions)	Landholders, managers	Enter postcode/location – lists species options	Fact sheets for different species/industry	http://www.farmdiversity.com.au/
Plot, stand and farm	Farm Forestry tool box	late 1990's;	Desktop program	Timber/wood products, carbon accounting across a variety of markets; oil mallee, sandalwood, euc and pines	Suite of models including; empirical and process-based growth models, empirical economic and carbon calculators. Health monitoring and diagnostics.	Forestry managers and landholders	Select tool and specific conditions	Growth rates	http://www.pft.tas.gov.au/services/services/farm_forestry_toolbox_-_version_5.3.8b
Plot, stand	Reforestation modelling tool	2011	Stand alone desktop app.	Carbon accounting	Empirical - FullCAM	Forestry managers and landholders	Select location, management, species and rotation type	Stand-level carbon yields	Dept. of Environment and Energy, Commonwealth. Also CFI mapping tool and FullCAM.
Farm scale	Shelter For Lambing Tool	?	Web-based tool	Whole-farm profitability of shelterbelts in sheep and wool grazing systems	Empirical economic model based on MIDAS	Farmers	Excel spreadsheet – input farm/site details	Net farm income after shelterbelt establishment	Evergraze - (http://www.evergraze.com.au/library-content/shelter-investment-tool/)
Regional management decision making	Landscape Futures Analysis Tool (LFAT)	2013	Web-based tool (http://lfat	Agricultural production, carbon sequestration,	Integrated assessment and modelling. Ag productivity – profit function; carbon – multi-	Policy makers, regional planners. Limited to two	Map-based. User defines scenarios including;	Suitability mapping of go/no-go areas	Uni of Adelaide, Environment Institute. User guide (http://lfat.org.au/lfat/

	.org.au/LF AT/Tool)	biodiversity, weed management	criteria analysis; biodiversity – cost- effectiveness approach; weeds – risk analysis.	NRM regions in SA.		docs/LandscapeFutures _UserGuide_FinalEbook .pdf)

5.2 Natural capital accounting of agroforestry

The concept of accounting for natural capital and the services that flow from it is starting to attract increasing attention both internationally and in Australia. Natural capital can be defined as the stock of natural assets including geology, soil, air, water and living things, from which humans gain benefits. From this natural capital base humans derive a range of services (ecosystem services) that are broadly categorised as:

- Provisioning services-products that ecosystems produce such as, food and water (Figure 5).
- Regulating services; natural processes regulated by ecosystems such as flood control, erosion control and pest and pathogen regulation (Figure 5).
- Cultural services-benefits obtained from ecosystems such recreation and spiritual values.
- Supporting services: services that maintain the condition for life on earth, e.g. photosynthesis (Figure 5).

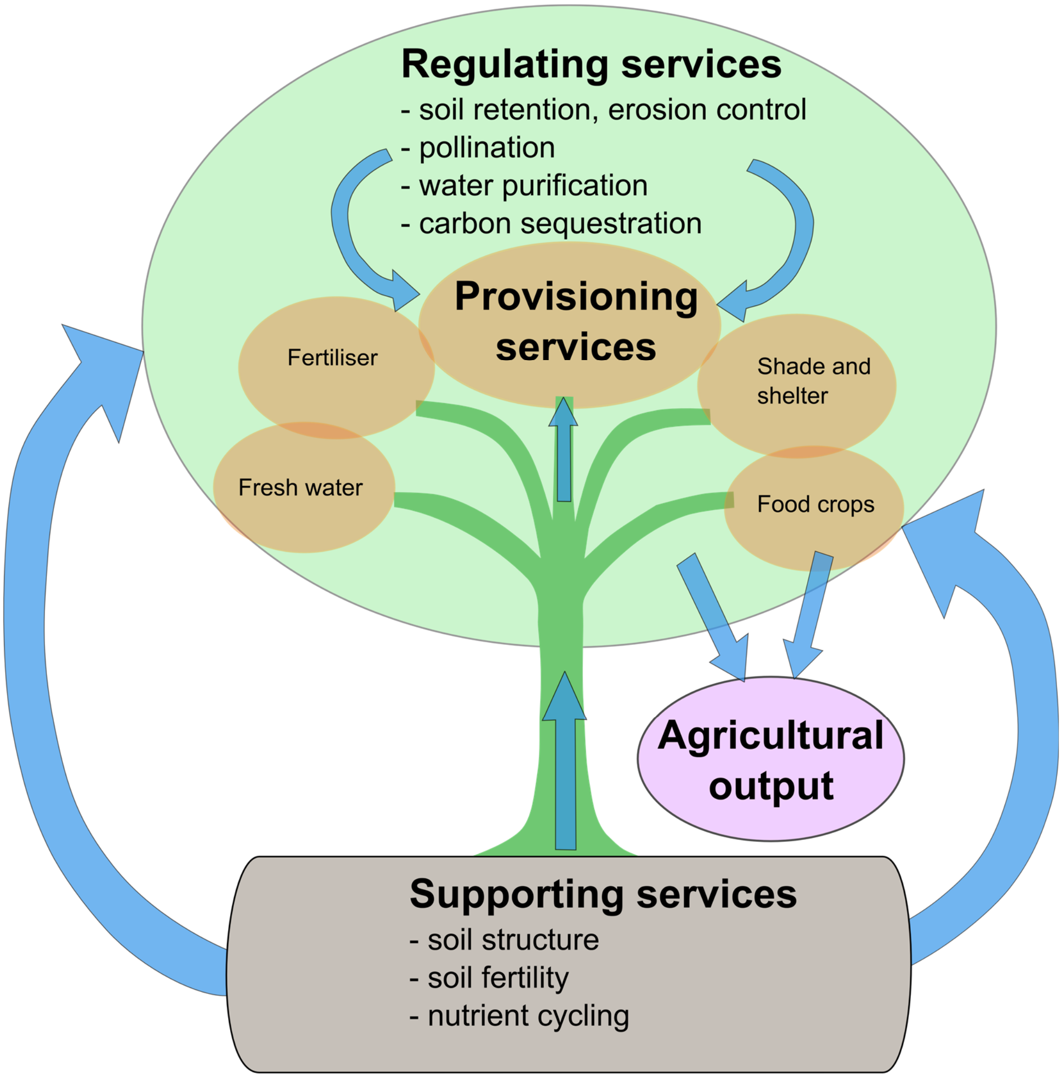

Figure 5 Conceptualisation of the dependencies of agricultural production on the inputs of environmental services (redrawn from Aisbett and Kragt 2010)

Farm forestry proponents have often expounded the values and services that flow from incorporating farm forestry in the landscape. But to date there have been surprisingly few attempts to analyse these additional costs and benefits within a formalised benefit cost ratio analysis. This is partly due to two factors:

- It is not normal to include these externalities into a farm scale benefit cost analysis.
- The valuation of ecosystem services is a difficult and complicated task (Edens & Hein, 2013).

Typically, the literature has viewed agricultural activities from the perspective of the impacts of agricultural activities on ecosystem services (Sandhu *et al.*, 2012, Baral *et al.*, 2013). Landcare policy in Australia, and much of the agroforestry literature tends to reflect this viewpoint, i.e. agroforestry can reduce agriculture's impact on environmental services see for example (Bari & Schofield, 1991,Ramachandran Nair *et al.*, 2009). However, agricultural productivity is intimately linked to the ecosystem services it receives, for example soil structure and fertility, nutrient cycling, soil retention: crop pollination, water provision etc. (Figure 5). Few studies have attempted to quantify the contribution of one or more ecosystem services to agricultural production (Aisbett & Kragt, 2010). This approach explicitly places value on the ecosystems services that enables agricultural production. A challenge then is quantifying and valuing the ecosystem services that agricultural output is dependent upon.

There is a large body of literature on the valuation of ecosystem services, and there are many approaches to valuing ecosystem services - these largely fall into two classes market and non-market valuations. Aisbett and Kragt (2010) argue that as markets already exist for agricultural products, market based valuations are likely to be the most appropriate to value ecosystem services and flows as inputs to agricultural production. Typical valuation approaches include production functions, hedonic pricing and replacement cost techniques. Aisbett and Kragt (2010) describe each of these in more detail but briefly:

- Production functions are based on the contribution of a given ecosystem service to the production of a commodity that is traded in existing markets.
- Replacement cost techniques are based on estimating the costs that would be incurred by replacing ecosystem services with artificial technologies.
- Hedonic pricing can be used to determine how ecosystem services impact agricultural land values.

However, there are few studies that have attempted this type of ecosystem valuation. Sandhu *et al.* (2008) examined used a range of approaches to value ecosystem services on arable lands of the Canterbury Plains in New Zealand. Recognising that shelterbelts provide a range of services to the adjoining agricultural land including: minimising soil erosion, improving microclimate and shelter and providing pollen and nectar resources to both pollinators and natural agents that perform biological control of pests and diseases. They used a production function approach to estimate the value of the ecosystem services associated with shelter belts in organic and conventional farming systems. A model of shelter belt permeability and yield was used to estimate the resultant changes in yield and this provided an estimate of the economic services provided by shelter belts. They determined that the value the environmental services of shelterbelts in organic systems was US $880 ha^{-1} yr^{-1} *versus* US $200 ha^{-1} yr^{-1} in conventional systems.

URS Forestry (2003) conducted an economic evaluation of the ecosystem service values from farm forestry. Although this exercise was primarily aimed at assessing the value of the environmental services as an externality they estimated the direct and indirect value of the private benefits of the services associated with farm forestry on a review of ecosystem service valuations, acknowledging that the approach should only be used as a guide and that the values were probably unreliable (Table 7). However, URS Forestry (2003) argued that this was reasonable as these values would either be ignored or given infinitely large values that were of little utility. While potentially coarse, the total value of the suite of environmental services provided by the shelterbelt were smaller than that estimated by Sandhu *et al.* (2008) but comparison is difficult because of the differences in the approaches used to estimate value and the overall lack of case studies that have attempted to estimate the value of environmental services as inputs, rather than outputs. Interestingly in that study the estimated value of non-market benefits including biodiversity, water quality and aesthetics was an additional \$95 ha^{-1} yr^{-1}. This highlights that based on this one study the direct benefits of the environmental services provided to the farm enterprise outweigh the value of the environmental services considered as public good.

Table 7 Estimates of the direct value to the farm enterprise that flow from shelter belts based on the study by URS Forestry (2003).

BENEFIT TYPE	SERVICE	ESTIMATE \$ HA^{-1} YR^{-1}
Direct	Carbon sequestration	100
Indirect	Crop and Livestock shelter	20
	Fodder	7
	salinity	10
	Soil erosion	7
Total		144

While there is increasing awareness that the future profitability and sustainability of agricultural enterprises are intimately linked to the natural capital (Sandhu *et al.*, 2012, Sandhu *et al.*, 2008, Ogilvy, 2015, Ogilvy & Kulkani, 2015) it also acknowledged that the frameworks for incorporating natural capital into the balance sheet of farming enterprises is missing. Despite this, many financial institutions and many customers along the value chain are responding to increasing pressure from consumers to explicitly account for and monitor their natural capital dependencies.

"*Natural capital is not a footnote in a business plan, it is a core asset on the balance sheet. That's true for an individual business; and its true also for the nation*" Ken Henry Chairman NAB, Fiona Wain Oration 31 May 2016

Additional benefits may flow to the farm enterprise through adoption of natural capital accounting, for example the National Australia Bank (NAB) is explicitly incorporating natural capital in their credit risk calculations to enable landholders who manage their land well to attract "*competitive risk-based prices on their debt, premium prices for their land and to communicate to high value markets that their produce is sustainable*". NAB currently offers a 0.7% interest rate discount on equipment finance for qualifying energy efficient assets. NAB is also the only Australian bank to sign the Natural Capital Declaration, an initiative of the Natural Capital Finance

Alliance that explicitly calls on the global finance community to build an understanding of the dependencies on natural capital, develop methodologies that incorporate natural capital into decision making, collaborate with international community to build a global consensus and incorporation of natural capital and work towards global standards for the integration of natural capital thinking into sector accounting and decision making. Industries that adopt natural capital thinking may be able to access premium markets. Indeed lack of environmental credentials can result in reduced market share and or lower prices for products. For example, cotton that meets best practice standards of the Better Cotton Initiative has attracted a premium of $3-7 per bale, and B&Q Kingfisher, one of the world's largest retail outlets specify Forest Stewardship Council certification for all of the wood products it sells.

Ogilvy (2015) presented a conceptual framework for "developing the ecological balance sheet". She adopts the term ecological capital to refer to the soils, vegetation, livestock and water that agricultural enterprises depend on. The term ecological capital is used over the more common natural capital to distinguish agricultural systems from more natural relatively undisturbed systems. Noting that current accounting standards for agriculture already implicitly include ecological capital, but lack a framework for double entry book keeping, Ogilvy developed an ecological balance sheet to record the stocks of ecological assets and the changes to these stocks that result from actions and transactions.

While it is still in its infancy, the valuation of ecosystem services and the capacity to develop balance sheets that explicitly incorporate the changes in stocks and flow of services that are associated with agroforestry may assist in overcoming farmer perceptions that the value of agroforestry is largely externalised. However to do so requires addressing many gaps in knowledge. There have been no systematic evaluations of types of services and the valuation of these services that flow from different agroforestry systems e.g. monoculture vs revegetation project, configuration etc. This will be challenging as the value of a project will need to be assessed as both a function of its interaction with natural capital and the motivations of the proponent. While many farming systems models exist that can directly predict increased yield in relation to agroforestry using approaches such as those presented by Sandhu *et al.* (2008), many ecosystem services are ignored or models don't account for changes in the stocks of the ecological capital. Similarly, the services that flow from natural capital are complex and difficult to directly measure, thus require the development and validation of suitable indices. The identification of appropriate indicators is critical, and is a science in its own right, but some characteristic features are that they can be used to measures trends and rates of change. Characteristics of useful indicators should:

- Be representative of the attribute that is being tracked.
- Be tractable for measuring, modelling and monitoring.
- Have data available over an appropriate baseline to establish reference conditions.
- Be amenable to characterising uncertainty.
- Be efficient, i.e. be useful in tracking trends and condition for multiple environmental services.

Examples of potential indicators for a range of provisioning and regulating services is shown in Table 8.

Table 8 The extent to which agroforestry systems can deliver specific provisioning services (commodity, complementarity and environmental) based on the findings of this review. The service delivery potential is based

on how likely the service will be realised given current economic and other considerations. An example of suitable indicators of different services is given. Note: h = high, m = medium, l = low.

SERVICES	INDICATORS	STOCK MONOCULTURE	SHELTER BELTS	ENV. PLANTINGS	NATIVE REMNANT	SERVICE DELIVERY POTENTIAL
Commodity						
Timber products	MAI	h	l	na	m*	m-h
Carbon	CO2 equivalent	h	m	h	m-h	l-m
Biofuel	Kg ha^{-1} MAI	h	l	l	m-h	l
Essential oils	Kg ha^{-1}	h	l	l	l	m
Complementarity	Tree height, porosity					
Crop	yield	l	m	l-m	l	m
Pasture	yield	l	m	l	l	m
Livestock	Survivorship, yield (milk, wool, weight gain)	l	m	l	m	m
Environ. services						
Soil conservation	Erosibility, ground cover	l-m	m	h	h	m
Nutrient management	Stream N and P and turbidity	m	l	m	m	m
Habitat provision	Spp. diversity, tree cover, length/area ratio	m	m	h	h	m
Pollination		l	l	h	h	m
Pest management	Pesticide usage	l	m	m	m	m

References

AFPA (2016) A national institute for forest products innovation. CAnberra, Australian Forest Products Association.

Aisbett E, Kragt M (2010) Valuing ecosystem services to agricultural production to inform policy design: An introduction. pp 25, Canberra, Crawford School of Economics and Government.

Anderson G (1986) The Effects of Trees on Crop and Animal Production. Trees and Natural Resources, **28**.

Archibald RD, Craig MD, Bialkowski K, Howe C, Burgess TI, Hardy GESJ (2011) Managing small remnants of native forest to increase biodiversity within plantation landscapes in the south west of Western Australia. Forest Ecology and Management, **261**, 1254-1264.

Australia Co (2016) Transforming Australia forest products industry: recommendations from the Forest Industry Advisory Council. pp 19, Canberra, Forest Industry Advisory Council, Department of Agriculture and Water Resources.

Ausubel JH, Wernick IK, Waggoner PE (2013) Peak Farmland and the Prospect for Land Sparing. Population and Development Review, **38**, 221-242.

Bailey R (2013a) The trouble with biofeuls: costs and consequences of expanding biofeul use in the United Kingdom. pp 25, London, Chatham House.

Bailey T (2013b) Plantings for carbon, biodiversity and restoration in dry rural landscapes. Australian Forest Grower, **35**, 39.

Baral H, Keenan RJ, Fox JC, Stork NE, Kasel S (2013) Spatial assessment of ecosystem goods and services in complex production landscapes: a case study from south-eastern Australia. Ecological Complexity, **13**, 35-45.

Bari MA, Schofield NJ (1991) Effects of agroforestry-pasture associations on groundwater level and salinity. Agroforestry Systems, **16**, 13-31.

Barnes P, Wilson BR, Reid N, Koen TB, Lockwood P, Lamb DW (2011) Litterfall and associated nutrient pools extend beyond the canopy of scattered eucalypt trees in temperate pastures. Plant and Soil, **345**, 339-352.

Bennell M, Hobbs TJ, Ellis M (2009) Evaluating agroforestry species and industries for lower rainfall regions of south east Australia. In: *Joint Venture Agroforestry Program and the Future Farm Industries CRC.* Canberra.

Bennell MR, Verbyla AP (2008) Quantifying the response of crops to shelter in the agricultural regions of South Australia. Australian Journal of Agricultural Research, **59**, 950-957.

Bennett RG, Mendham D, Ogden G, Bartle J (2015) Enhancing tree belt productivity through capture of short-slope runoff water. GCB Bioenergy, **7**, 1107-1117.

Benyon RG, Polglase P (2009) The impacts of plantations and native forests on water security: Review and scientific assessment of regional issues and research needs. Canberra, Forests and Wood Products Australia.

Beverly C, Bari M, Christy B, Hocking M, Smettem K (2005) Predictied salinity impacts from land use change: comparison between a rapid assessment approach and a detailed modelling framework. Australian Journal of Experimental Agriculture, **45**, 1453-1469.

Bird PR, Lynch JJ, Obst JM (1984) Effect of shelter on plant and animal production. Proceedings of the Australian society of Animal Production, **15**, 270-273.

Booth TH (2012) Forest Landscape Restoration in Australia's Murray-Darling Basin. In: *A Goal-Oriented Approach to Forest Landscape Restoration.* pp 355-371. Springer.

Booth TH, Williams KJ, Belbin L (2012) Developing biodiverse plantings suitable for changing climatic conditions 2: Using the Atlas of Living Australia. Ecological Management & Restoration, **13**, 274-281.

Boreux V, Kushalappa CG, Vaast P, Ghazoul J (2013) Interactive effects among ecosystem services and management practices on crop production: Pollination in coffee agroforestry systems. Proceedings of the National Academy of Sciences, **110**, 8387-8392.

Boutland A, Robinson M, Field J *et al.* (1992) Alternative products from trees and shrubs to 'The role of trees in sustainable agriculture' conference, Albury, September 30th–October 3rd 1991. Agroforestry Systems, **20**, 25-58.

Boxshall B, Mitchell P (2008) Research and Development of *Casuarina obesa*. Albany, University of Western Australia.

Bradshaw CJA, Bowman DMJS, Bond NR *et al.* (2013) Brave new green world – Consequences of a carbon economy for the conservation of Australian biodiversity. Biological Conservation, **161**, 71-90.

Brand JE (2009) Effect of different Acacia acuminata variants as hosts on performance of sandalwood (Santalum spicatum) in the northern and eastern Wheatbelt, Western Australia. Australian Forestry, **72**, 149-156.

Brooksbank K, Lever M, Paterson H, Weyury M (2014) Biomass scoping study: opprtunities for agriculture in Western Australia. Perth, Department of Agriculture and Food, Western Australia.

Brooksbank K, Veneklaas EJ, White DA, Carter JL (2011) Water availability determines hydrological impact of tree belts in dryland cropping systems. Agricultural Water Management, **100**, 76-83.

Broster JC, Robertson SM, Dehaan RL, King BJ, Friend MA (2012) Evaluating seasonal risk and the potential for windspeed reductions to reduce chill index at six locations using GrassGro. Animal Production Science, **52**, 921-928.

Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology, **310**, 28-61.

Brown AG (2004) Blackwood management: learning from New Zealand. In: *Joint Venture Agroforetry Program.* pp 116, Rural industries Research and Development Corporation.

Bryan BA, Ward J, Hobbs T (2008) An assessment of the economic and environmental potential of biomass production in an agricultural region. Land Use Policy, **25**, 533-549.

Burns K, Hug B, Lawson K, Ahammad H, Zhang K (2011) Abatement potential from reforestation under selected carbon price scenarios. Canberra, ABARES Special Report, July 2011.

Bush D, Jackson T, Driscoll J, Harwood C (2009) Australian Low Rainfall Tree Improvement Group: Metadata from measures of hardwood tree improvement trials in Southern Australia. Canberra, Rural Inustries Research and Development, Publication No. 09/078.

Bush D, Pinkard E, Harwood C (2016a) Review of dryland plantation forestry opportunities in Australia. Canberra, CSIRO.

Bush D, Pinkard EA, Harwood CE (2016b) Reveiw of dryland plantation forestry opportunities in Australia. Canberra, CSIRO.

Buttoud G, Ajayi O, Detlefsen G, F. P, Torquebiau E (2013) Advancing Agroforestry on the Policy Agenda: A guide for decision-makers, . In: *Agroforestry Working Paper no. 1.* pp 37, Rome, Food and Agriculture Organization of the United Nations.

Campbell White and Associates, Black A (1999) Practical farm forestry. In: *Joint Venture Agroforestry Program.* Canberra, Rural Industries Research and Development Corporation.

Carberry PS, Meinke H, Poulton PL, Hargreaves JNG, Snell AJ, Sudmeyer RA (2002) Modelling crop growth and yield under the environmental changes induced by windbreaks. 2. Simulation of potential benefits at selected sites in Australia. Australian Journal of Experimental Agriculture, **42**, 887-900.

Catling P, Burt R (1995) Why are red foxes absent from some eucalypt forests in eastern New South Wales? Wildlife Research, **22**, 535-545.

Cavana RY, Glass BP (1985) Economic analysis of selected special-purpose species regimes. New Zealand Journal of Forestry Science, **15**, 180-194.

CEFC (2015) The Australia bioenergy ad energy from waste market. pp 15, Clean Energy Finance Corporation.

Centre for International Economics (2012) The case for renewed development in plantations: Identifying forest values and the constraints to attainment – Stage one. Melbourne, Forest and Wood Products Australia.

Chudleigh P, Thomy B, Bath A (2013) Economic evaluation of investment in Essential Oils and Plant extracts R&D program. pp 78, Canberra, Rural Industries Research and Development Corporation.

Clarke B, Mcleod I, Vercoe T (2009) Trees for farm forestry: 22 promising species. In: *Joint Venture Agroforestry Program.* Canberra.

Cleugh HA, Hughes DE (2002) Impact of shelter on crop microclimates: a synthesis of results from wind tunnel and field experiments. Australian Journal of Experimental Agriculture, **42**, 679-701.

Cleugh HA, Prinsley R, Bird PR *et al.* (2002) The Australian National Windbreaks Program: overview and summary of results. Australian Journal of Experimental Agriculture, **42**, 649-664.

Crawford DF, O'Connor MH, Jovanovic T, Herr A, Raison RJ, O'Connell DA, Baynes T (2016) A spatial assessment of potential biomass for bioenergy in Australia in 2010, and possible expansion by 2030 and 2050. GCB Bioenergy, **8**, 707-722.

Crossman ND, Bryan BA, Summers DM (2011) Carbon Payments and Low-Cost Conservation

Pagos de Carbono y Conservación de Bajo Costo Conservation Biology, **25**, 835-845.

Current D, Lutz E, Scherr SJ (1995) The costs and benefits of agroforestry to farmers. The World Bank Research Observer, **10**, 151-180.

Dames & Moore NRM, FORTECH (1999) Integrating Farm Forestry and Biodiversity. Canberra, Rural Industries Development Corporation.

Defenderfer D (2010) Carbon storage and trading through farm forestry: A survey of farmers in Tasmania. pp 15, Hobart, Private Forests Tasmania.

Dicks LV, Viana B, Bommarco R *et al.* (2016) Ten policies for pollinators. Science, **354**, 975-976.

Downham R, Gavran M (2017) Australian plantation statistics 2017 update. Canberra, ABARES.

Dumbrell NP, Kragt ME, Gibson FL (2016) What carbon farming activities are farmers likely to adopt? A best–worst scaling survey. Land Use Policy, **54**, 29-37.

Duncan DH, Dorrough J, White M, Moxham C (2008) Blowing in the wind? Nutrient enrichment of remnant woodlands in an agricultural landscape. Landscape Ecology, **23**, 107-119.

Dye P, Versfeld D (2007) Managing the hydrological impacts of South African plantation forests: An overview. Forest Ecology and Management, **251**, 121-128.

EBONS (2015) THE ECONOMIC BENEFITS OF NATIVE SHELTER BELTS REPORT. Basalt to Bay Landcare Network.

Eby P (2015) Planting to conserve threatened nomadic pollinators. pp 26, Sydney, Office of environment and Heritage, NSW.

Edens B, Hein L (2013) Towards a consistent approach for ecosystem accounting. Ecological Economics, **90**, 41-52.

Ellis TW, Leguédois S, Hairsine PB, Tongway DJ (2006) Capture of overland flow by a tree belt on a pastured hillslope in south-eastern Australia. Soil Research, **44**, 117-125.

EU (2012) Innovating for sustainble growth: A bioeconomy for europe. Brussels, European Commission.

Farine DR, O'Connell DA, John Raison R *et al.* (2012) An assessment of biomass for bioelectricity and biofuel, and for greenhouse gas emission reduction in Australia. GCB Bioenergy, **4**, 148-175.

Farquharson R, Abadi A, Finlayson J *et al.* (2013) Everfarm® – Climate adapted perennial-based farming systems for dryland agriculture in southern Australia. pp 164, National Climate Change Adaptation Research Facility.

Fenton J (2010) *The untrained environmentalist: How an Australian grazier bought his barren propoerty back to life,* Sydney, Allen and Unwin.

Ferwerda F (2003) Assessing the importance of remnant vegetation for maintaining biodiversity in rural landscapes using geospatial analysis. Unpublished MSc Royal Melbourne Institute of Technology.

Forests N (2015) Timberland investment outlook 2015-2019. New Forests.

Freundenberger D, Cawsey EM (2005) Biodiversity Benefits of Commercial Environmental Forestry: The Plantation Biodiversity Score. Canberra, CSIRO Sustainable Ecosystems.

Fritsch S, Hudson B (2008) Whole farm financial and environmental returns inder farm forestry. Six case studies. In: *Joint Venture Agroforestry Program.* pp 51, Canberra, Rural Industries research and development corporation.

Garibaldi LA, Steffan-Dewenter I, Winfree R *et al.* (2013) Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. Science, **339**, 1608-1611.

Garrity DP (2004) Agroforestry and the achievement of the Millennium Development Goals. Agroforestry Systems, **61**, 5-17.

George RJ, Nulsen RA, Ferdowsian R, Raper GP (1999) Interactions between trees and groundwaters in recharge and discharge area: A survey of Western Australian sites. Agricultural Water Management, **39**, 91-113.

Greenwood EAN, Klien L, Beresford JD, Watson GD (1985) Differences in annual evapotranspiration between grazed pasture and *Eucalyptus* species in plantations on a saline farmland catchment. Journal of Hydrology, **78**, 261-278.

Grimbacher P (2011) Biodiversity Outcomes from Eucalypt Plantation Expansion into Agricultural Landscapes of Southern Australia: A Review. Cooperative Research Centre for Forestry, Hobart, Tasmania. Technical Report 215.

Group W (2008) Accounting for Nature: A model for building the National Environmental Accounts of Australia. Wenthorth Group of Concerned Scientists.

Hairsine P, van Dijk A (2006) Comparing the in-stream outcomes of commercial and environmental tree plantings. In: *CSIRO Land and Water Science Report 11/06.* CSIRO Land and Water Science Report 11/06.

Hajkowicz S, Moody J (2010) Our future world. An analysis of global trends, shocks and scenarios. Canberra, CSIRO.

Harrison PA, Vaillancourt RE, Harris RMB, Potts BM (2017) Integrating climate change and habitat fragmentation to identify candidate seed sources for ecological restoration. Restoration Ecology, n/a-n/a.

Harrison S, Herboln J (2008) Agroforestry and Farm Forestry: Support systems to assess the viability of whole farm and regional agroforestry enterprises. Canberra, Rural Industries Research and Development Corporation.

Hassall A (2008) Quantifying the value of farm forestry. pp 56, CAnberra, Rural industries Research and Development Corporation.

Hawke M, O'Connor M (1993) Soil pH and nutrient levels at Tikitere agroforestry research area. New Zealand Journal of Forestry Science, **23**, 40-48.

Hean R, Cacho O, Signor A, Mullen (2000) The Potential Role of Farm Forestry in the Wheat-Sheep Zone of NSW In: *Annual Conference of the Australian Agricultural and Resources Economics Society.* Sydney.

Herbohn JL, Harrison S, Emtage N, Norman P (2008) *The current status of farm forestry in Australia. In* Canberra, Rural Industries Research and Development Corporation.

Hobbs TJ (2009) Reveiw of wood products, tannins and exotic species for agroforestry in lower rainfall regions of southern Australia, FloraSearch. In: *Joint Venture Agroforestry Program.* Rural Industries Research and Development Corporation.

Hobbs TJ, Bennell M, Huxtable D *et al.* (2009) Potential agroforestry species and regional industries for lower rainfall southern Australia. Canberra, Report to the Joint Venture Agroforestry Program (JVAP) and the Future Farm Industries CRC.

Hobbs TJ, Georgaras P., Tiucker M, Neumann C, Bennell M (2006) Woody biomass productivity and potential biomass industries in the upper south east. pp 138, SA Department of Water, Land and Biodiversity, Co-operative Research Centre for Plant-based management of Dryland Salinity.

Huang HQ, Nanson GC (1997) Vegetation and channel variation; a case study of four small streams in southeastern Australia. Geomorphology, **18**, 237-249.

Hulvey KB, Hobbs RJ, Standish RJ, Lindenmayer DB, Lach L, Perring MP (2013) Benefits of tree mixes in carbon plantings. Nature Clim. Change, **3**, 869-874.

Jackson J, Ash AJ (2001) The role of trees in enhancing soil nutrient availability for native perennial grasses in open eucalypt woodlands of north-east Queensland. Australian Journal of Agricultural Research, **52**, 377-386.

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, **76**, 1-10.

Kaczan D, Arslan A, Lipper L (2013) Climate-Smart Agriculture? A review of current practice of agroforestry and conservation agriculture in Malawi and Zambia

Food and Agriculture Organization of the United Nations.

Kaiser-Bunbury CN, Mougal J, Whittington AE, Valentin T, Gabriel R, Olesen JM, Blüthgen N (2017) Ecosystem restoration strengthens pollination network resilience and function. Nature, **542**, 223-227.

Keogh RC, Robinson APW, Mullins IJ (2010) Pollination aware: the real value of pollination in Australia. Canberra, Rural Industries Research and Devlopment Corporaion.

Kingwell RS, Pannell DJ (1987) *MIDAS. A Bioeconomic Model of a Dryland Farm System,* Wageningen, Pudoc.

Kirby MC, Sinden JA, Kaine GW (1993) Appraisal of agroforestry investment under uncertainty: A South Australian case study. Australian Forestry, **56**, 109-119.

Kormann U, Scherber C, Tscharntke T *et al.* (2016) Corridors restore animal-mediated pollination in fragmented tropical forest landscapes. Proceedings of the Royal Society B: Biological Sciences, **283**.

Langford KJ (1976) Change in yield of water following a bushfire in a forest of eucalyptus regnans. Journal of Hydrology, **29**, 87-114.

Lin BB, Macfadyen S, Renwick AR, Cunningham SA, Schellhorn NA (2013) Maximizing the Environmental Benefits of Carbon Farming through Ecosystem Service Delivery. BioScience, **63**, 793-803.

Lindenmayer DB, Hobbs RJ (2004) Fauna conservation in Australian plantation forests – a review. Biological Conservation, **119**, 151-168.

Lindenmayer DB, Hulvey KB, Hobbs RJ *et al.* (2012) Avoiding bio-perversity from carbon sequestration solutions. Conservation Letters, **5**, 28-36.

Lynch J, Donnelly J (1980) Changes in pasture and animal production resulting from the use of windbreaks. Australian Journal of Agricultural Research, **31**, 967-979.

Malajczuk G, Moore R, Anderson G (1996) The economics of agroforestry with pine and pasture in the 500 to 700 mm annual rainfall zone of Western Australia. Agroforestry Systems, **33**, 51-74.

Marcar N, Crawford D, Leppert P, Jovanovic T, Floyd R, Farrow R (1995) *Trees for Saltland: a Guide to Selecting Native Species for Australia,* Melbourne, CSIRO Publications.

Matysek AL, Fisher BS (2016) The economic potential for plantation expansion in Australia. pp 78, Canberra, BAEconomics.

Mbow C, Noordwijk Mv, Prabhu R, Simons AJ (2014) Knowledge gaps and research needs concerning agroforestry's contribution to sustainable development goals in Africa. Current Opinion in Environmental Sustainability, **6**, 162-170.

McCaskill M, Clark S (2007) EverGraze 4. Wind roses for "bad" lambing weather. In: *Proceedings of the 48th annual conference of the Grassland Society of Southern Australia.* pp 103, Grassland Association of Southern Australia Inc.: Echuca, Vic.

McJannet DL, Vertessy RA, Clifton CA (2000) Observations of evapotranspiration in a break of slope plantation susceptible to periodic drought stress. Tree Physiology, **20**, 169-177.

Mendham D, Drew D, Abadi A, Bartle J, Peck A, Crawford D (2015) Potential cineole cost and availbility from Malle euclaypt shelterbelt plantations in Western Australia. pp 24, Hobart, CSIRO Land and Water.

Mendham DS, Heagney EC, Corbeels M, O'Connell AM, Grove TS, McMurtrie RE (2004) Soil particulate organic matter effects on nitrogen availability after afforestation with Eucalyptus globulus. Soil Biology and Biochemistry, **36**, 1067-1074.

Menz MHM, Phillips RD, Winfree R, Kremen C, Aizen MA, Johnson SD, Dixon KW (2011) Reconnecting plants and pollinators: challenges in the restoration of pollination mutualisms. Trends in Plant Science, **16**, 4-12.

Mitchell CD, Harper RJ, Keenan RJ (2012) Current status and future prospects for carbon forestry in Australia. Australian Forestry, **75**, 200-212.

Moore R (1992) Integrating wood production into Australia farming systems. Agroforestry Systems, **20**, 167-186.

Morrow A (2007) Evaluation of Australian timbers for use in musical instruments. In: *2007 Gottstein Fellowship report.* pp 146, Clayton Victoria, Gottstein Trust.

Myers BJ, Bond WJ, Benyon RG *et al.* (1999) Sustainable effluent-irrigated plantations: an Australian guideline. Canberra, CSIRO Forestry and Forest Products.

Myers BJ, Theiveyanathan S, O'Brien ND, Bond WJ (1996) Growth and water use of Eucalyptus grandis and Pinus radiata plantations irrigated with effluent. Tree Physiology, **16**, 211-219.

Nair PKR (1993) *An introduction to Agroforestry,* Dordrecht, Kluwer Academic Publishers.

Nair PKR, Kang BT, Kass DCL (1995) Nutrient Cycling and Soil-Erosion Control in Agroforestry Systems. In: *Agriculture and Environment: Bridging Food Production and Environmental Protection in Developing Countries.* (eds Juo ASR, Freed RD) pp 117-138. Madison, WI, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Nicholas I, Brown I (2008) *Best Practice with Fram Foretry Tiber Species. No 4: Blackwood*, New Zealand Farm Forestry Association.

NPI (2016) Australian plantation statistics 2016. pp 52, Canberra, Department of Agriculture and Water Resources.

Nuberg I, Bennell M (2009) Trees protecting dryland crops and soil. Agroforestry for natural resource management, 69-85.

Ogilvy S (2015) Developing the Ecological Balance Sheet for Agricultural Sustainability. Sustainability Accounting, Management and Policy Journal, **6**, 110-137.

Ogilvy S, Kulkani A (2015) From vicious to virtuous cycles: the future of Australian agriculture. Centre for policy development.

Oliver YM, Lefroy EC, Stirzaker R, Davies CL (2005) Deep-drainage control and yield: the trade-off between trees and crops in agroforestry systems in the medium to low rainfall areas of Australia. Australian Journal of Agricultural Research, **56**, 1011-1026.

Pannell DJ (1999) Social and economic challenges in the development of complex farming systems. Agroforestry Systems, **45**, 395-411.

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R (2006) Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture, **46**, 1407-1424.

Parkes D, Newell G, Cheal D (2003) Assessing the quality of native vegetation: The 'habitat hectares' approach. Ecological Management & Restoration, **4**, S29-S38.

Parliament of the Commonwealth (2014) Carbon Farming Initiative Amendment Bill, Explanatory Memorandum. Canberra, ACT, Parliament of the Commonwealth of Australia.

Patabendige D, Scott P, Lefroy E Fodder Trees and Shrubs for High Rainfall Areas of South Western Australia. In: *Resource Management Technical Report No.135.* Department of Agriculture, Western Australia.

Paul KI, Reeson A, Polglase P, Crossman N, Freudenberger D, Hawkins C (2013a) Economic and employment implications of a carbon market for integrated farm forestry and biodiverse environmental plantings. Land Use Policy, **30**, 496-506.

Paul KI, Reeson A, Polglase PJ, Ritson P (2013b) Economic and employment implications of a carbon market for industrial plantation forestry. Land Use Policy, **30**, 528-540.

Polglase P, Paul K, Hawkins C *et al.* (2008a) Regional Opportunities for Agroforestry Systems in Australia. Canberra, RIRDC Publication No. 081176.

Polglase P, Reeson A, Hawkins C *et al.* (2011) Opportunities for carbon forestry in Australia:economic assessment and constraints to implementation. Canberra, CSIRO.

Polglase PJ, Paul KI, Hawkins C *et al.* (2008b) Regional opportunities for agroforestry systems in Australia. In: *Joint Venture Agroforestry Program.* pp 111, Canberra, Rural Industries Research and Development Corporation.

Polglase PJ, Reeson A, Hawkins CS *et al.* (2013) Potential for forest carbon plantings to offset greenhouse emissions in Australia: economics and constraints to implementation. Climatic Change, **121**, 161-175.

Potts SG, Imperatriz-Fonseca V, Ngo HT *et al.* (2016) Safeguarding pollinators and their values to human well-being. Nature, **540**, 220-229.

Powell J (2009) Fifteen years of Joint Venture Agroforestry proogram-Foundation for Australiua tree crop revolution. Canberra, Rural Industries Research and Development Corporation.

Prinsley RT (1992) The role of trees in sustainable agriculture — an overview. Agroforestry Systems, **20**, 87-115.

Ramachandran Nair PK, Mohan Kumar B, Nair VD (2009) Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science, **172**, 10-23.

Rassam DW, Pagendam DE, Hunter HM (2008) Conceptualisation and application of models for groundwater–surface water interactions and nitrate attenuation potential in riparian zones. Environmental Modelling & Software, **23**, 859-875.

Reeson A, Rudd L, Zhu Z (2015) Management flexibility, price uncertainty and the adoption of carbon forestry. Land Use Policy, **46**, 267-272.

Reid R, Stephen P (eds) (2001) *The farmers forest: multipurpose forestry for Australian Famers*.

Repo A, Känkänen R, Tuovinen J-P, Antikainen R, Tuomi M, Vanhala P, Liski J (2012) Forest bioenergy climate impact can be improved by allocating forest residue removal. GCB Bioenergy, **4**, 202-212.

Reynolds IK, Sinden JA (1979) Cost of land management for amenity in multiple use policies. Australian Forestry, **42**, 236-242.

Robertson SM, Friend MA, Broster JC, King BJ (2011) Survival of twin lambs is increased with shrub belts. Animal Production Science, **51**, 925-938.

Rothe A, Moroni M, Neyland M, Wilnhammer M (2015) Current and potential use of forest biomass for energy in Tasmania. Biomass and Bioenergy, **80**, 162-172.

Ruprecht J (2004) Plantations act as pumps for salinity management. In: *Australian Forest Grower.* Canberra.

Salt D, Lindenmayer D, Hobbs R (2004) Trees and biodiversity: A guide for Australian farm forestry. Joint Venture Agroforestry Program. RIRDC publication number: 03/047.

Sandhu HS, Crossman ND, Smith FP (2012) Ecosystem services and Australian agricultural enterprises. Ecological Economics, **74**, 19-26.

Sandhu HS, Wratten SD, Cullen R, Case B (2008) The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics, **64**, 835-848.

Scheper J, Holzschuh A, Kuussaari M, Potts SG, Rundlöf M, Smith HG, Kleijn D (2013) Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. Ecology Letters, **16**, 912-920.

Schmitt T, Dosskey M, Hoagland K (1999) Filter strip performance and processes for different vegetation, widths, and contaminants. Journal of Environmental Quality, **28**, 1479-1489.

Sharma N, Bohra B, Pragya N, Ciannella R, Dobie P, Lehmann S (2016) Bioenergy from agroforestry can lead to improved food security, climate change, soil quality, and rural development. Food and Energy Security, **5**, 165-183.

Smethurst P, Petrone K, Baillie C, Worledge D, Langergraber G (2010) Streamside Management Zones for Buffering Streams on Farms: Observations and Nitrate Modelling. Technical Report no. 28. Landscape Logic.

Smith CJ, Snow VO, Polglase PJ, Probert ME (1999) Nitrogen dynamics in a eucalypt plantation irrigated with sewage effluent or bore water. Soil Research, **37**, 527-544.

Steffen W, Stock A, Alexander D, D. R (2017) Angry summer 2016/17: climate change super charging extreme weather. pp 24.

Stephens ML, Grist P (2014) Market Failure for Plantations: Past Experiences and Emerging Trends for Delivering Wood Production and Ecosystem Services in Australia. International Forestry Review, **16**, 205-215.

Stirzaker RJ, Cook FJ, Knight JH (1999) Where to plant trees on cropping land for control of dryland salinity:some approximate solutions. Agricultural Water Management, **39**, 115-133.

Stringfellow W, Canmarillo MK, Hanlon J, Jue M, Spier C (2011) Fiscalini Farms Biomass Energy Project Final Report 2011 University of the Pacific Ecological engineering research program.

Stucley C, Schuck S, Ralph Sims R *et al.* (2012) Bioenergy in Australia: Status and opportunities. pp 340, Sydney, Bioenergy Australia.

Stucley CR, Schuck SM, Sims REH, Larsen PL, Turvey ND, Marino BE (2004) Biomass Energy priduction in Australia; Staus, costs and opprotuities for major technologies. In: *Joint Veture Agroforestry Program.* Rural Industires Research and Development Corporation.

Suckling G, Backen E, Heislers A, Neumann F (1976) The flora and fauna of Radiata pine plantations in North-eastern Victoria. Forests Commission, Victoria, Bulletin no. 24.

Summers DM, Bryan BA, Meyer WS *et al.* (2015) Simple models for managing complex social–ecological systems: The Landscape Futures Analysis Tool (LFAT). Environmental Modelling & Software, **63**, 217-229.

Taylor DB, Schneider DA, Brown WY, Price IR, Trotter MG, Lamb DW, Hinch GN (2011) GPS observation of shelter utilisation by Merino ewes. Animal Production Science, **51**, 724-737.

Thomson JR, Moilanen AJ, Vesk PA, Bennett AF, Nally RM (2009) Where and when to revegetate: a quantitative method for scheduling landscape reconstruction. Ecological Applications, **19**, 817-828.

Thorrold BS, Knowles RL, Nicholas ID, Power IL, Carter JL (1997) Evaluation of agroforestry options for three tree species. Proceeding s of the New Zealand Grassland Association, **59**, 187-190.

Torabi N, Mata L, Gordon A, Garrard G, Wescott W, Dettmann P, Bekessy SA (2016) The money or the trees: What drives landholders' participation in biodiverse carbon plantings? Global Ecology and Conservation, **7**, 1-11.

Udawatta RP, Krstansky JJ, Henderson GS, Garrett HE (2002) Agroforestry Practices, Runoff, and Nutrient Loss. Journal of Environmental Quality, **31**, 1214-1225.

UNFCCC (2006) United Nations Framework Convention on Climate Change. (ed Bloble D, Meyer-Ohlendorf, N.) pp 220, Bonn, Germany.

URS (2008) Farm Forestry Area and Resources in Australia. pp 37, Canberra, Joint Venture Agroforestry Program.

URS Forestry (2003) Evaluation of Environmental Services Provided by Farm Forestry-a discussion paper. pp 68, Hobart, Private Forests Tasmania.

van der Moezel PG, Watson LE, Bell DT (1989) Gas exchange responses of two Eucalyptus species to salinity and waterlogging. Tree Physiology, **5**, 251-257.

van Dijk A, Austin J, Theveiyanathan T, Benyon R, Hairsine P (2004) Representing plantation scenarios in hydrological modelling: Requirements and limitations in representing Commercial Environmental Forestry scenarios in stream flow and salinity modelling. CSIRO Land and Water, Commercial Environmental Forestry report CLW/02.

van Noordwijk M, Mbow C, Minang PA (2015) Trees as nexus for sustainable development goals: agroforestry for integrated options. (ed margins APfttf), Nairobi, Kenya.

van Oosterzee P (2012) The integration of biodiversity and climate change: A contextual assessment of the carbon farming initiative. Ecological Management & Restoration, **13**, 238-244.

Varah A, Jones H, Smith J, Potts SG (2013) Enhanced biodiversity and pollination in UK agroforestry systems. Journal of the Science of Food and Agriculture, **93**, 2073-2075.

Vertessy RA, Watson FG, O' Sullivan SK (2001) Factors determining relations between stand age and catchment water balance in mountain ash forests. Forest Ecology and Management, **143**, 13-26.

Vesk PA, Mac Nally R (2006) The clock is ticking—Revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia. Agriculture, Ecosystems & Environment, **112**, 356-366.

Viney NR, Sivapalan M (2001) Modelling catchment processes in the Swan–Avon river basin. Hydrological Processes, **15**, 2671-2685.

Wang H, Takle ES (1997) MOMENTUM BUDGET AND SHELTER MECHANISM OF BOUNDARY-LAYER FLOW NEAR A SHELTERBELT. Boundary-Layer Meteorology, **82**, 417-437.

Ward B, Sparks T, Blake G (2011) Denmark River water resource recovery plan. Government of Western Australia, Department of Water.

Wildridge AM, Garcia SC, Thomson PC, Jongman EC, Clark CEF, Kerrisk KL (2017) The impact of a shaded pre-milking yard on a pasture-based automatic milking system. Animal Production Science, **57**, 1219-1225.

Young JM, Saul G, Behrendt R, Byrne F, McCaskill M, Kearney GA, Thompson AN (2014) The economic benefits of providing shelter to reduce the mortality of twin lambs in south-western Victoria. Animal Production Science, **54**, 773-782.

Zammit C, Sivapalan M, Kelsey P, Viney NR (2005) Modelling the effects of land-use modifications to control nutrient loads from an agricultural catchment in Western Australia. Ecological Modelling, **187**, 60-70.

Zhang L, Dawes WR, Walker GR (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resources Research, **37**, 701-708.

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