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Modelling the costs and benefits of Agroforestry systems

Application of the Imagine bioeconomic model at four case study sites in Tasmania.

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Executive summary

Integrating trees into agricultural production systems can provide a range of benefits that may add substantial value to farm enterprises. Here, the Imagine bioeconomic model was applied to agroforestry systems at four sites in Tasmania. The aim was to understand the costs and benefits of a range of *P. radiata* agroforestry system configurations (2 row belt, 5 row belt, 10 row belt, and 2 x 2 row belts) integrated with a livestock grazing enterprise, in comparison to the returns from either full pasture or full trees. The benefits from the trees that are accounted for by the Imagine model include the timber, amenity and carbon values, as well as the additional shelter benefits that trees provide to the adjacent agriculture. The results showed that a well-targeted agroforestry system can substantially improve paddock-level returns to farmers, with many of the returns arising from shelter benefits to the adjacent agriculture (both through reducing livestock mortality, and increasing pasture productivity), and occurring throughout the rotation, rather than just from final harvest. Almost all scenarios that were explored demonstrated that trees more than paid their way, and in fact, they increased the returns at the whole-paddock scale, with 2-row belts offering the greatest benefit in all situations. However, multiple- row belts may be more important for increasing the scale of the resource available on any one farm, and reducing the per-unit harvesting costs at the end of the rotation. The results from this study suggest that the traditional paradigm that agroforestry is better suited to land uses with low opportunity cost may be inaccurate, as most of the returns come from the benefits that the trees convey to the adjacent agriculture, rather than from the trees themselves.

1 Introduction

Integration of trees into agricultural production systems can convey a number of benefits that have potential to add substantial value to farm enterprises. However, many of these benefits are not commonly accounted for in the balance sheets for the tree component of the system. For example, most forestry land uses are expected to be profitable based on the economics of the final harvest of trees for wood, but this discounts the fact that trees can contribute much more than wood to the farm balance sheet during their life cycle (Baker et al, 2018). In fact, the benefits from trees can start to accrue not long after they are planted, including increasing the productivity of adjacent crops and livestock through shelter, sequestering carbon, increasing amenity and biodiversity, all of which can potentially add monetary value to the farm enterprise if properly accounted for. This study aimed to integrate the impacts of shelter, carbon sequestration, and amenity, as well as returns from traditional timber sales from different agroforestry system configurations. The system that we modelled here was *Pinus radiata* integrated into a sheep grazing enterprise at four case study sites in Tasmania. The Imagine bioeconomic model (reviewed by Greijdanus et al, 2014), has been adapted to allow it to model the shelter effects on pasture, and thus, livestock production. Imagine can also model the other benefits from the trees.

2 Methods

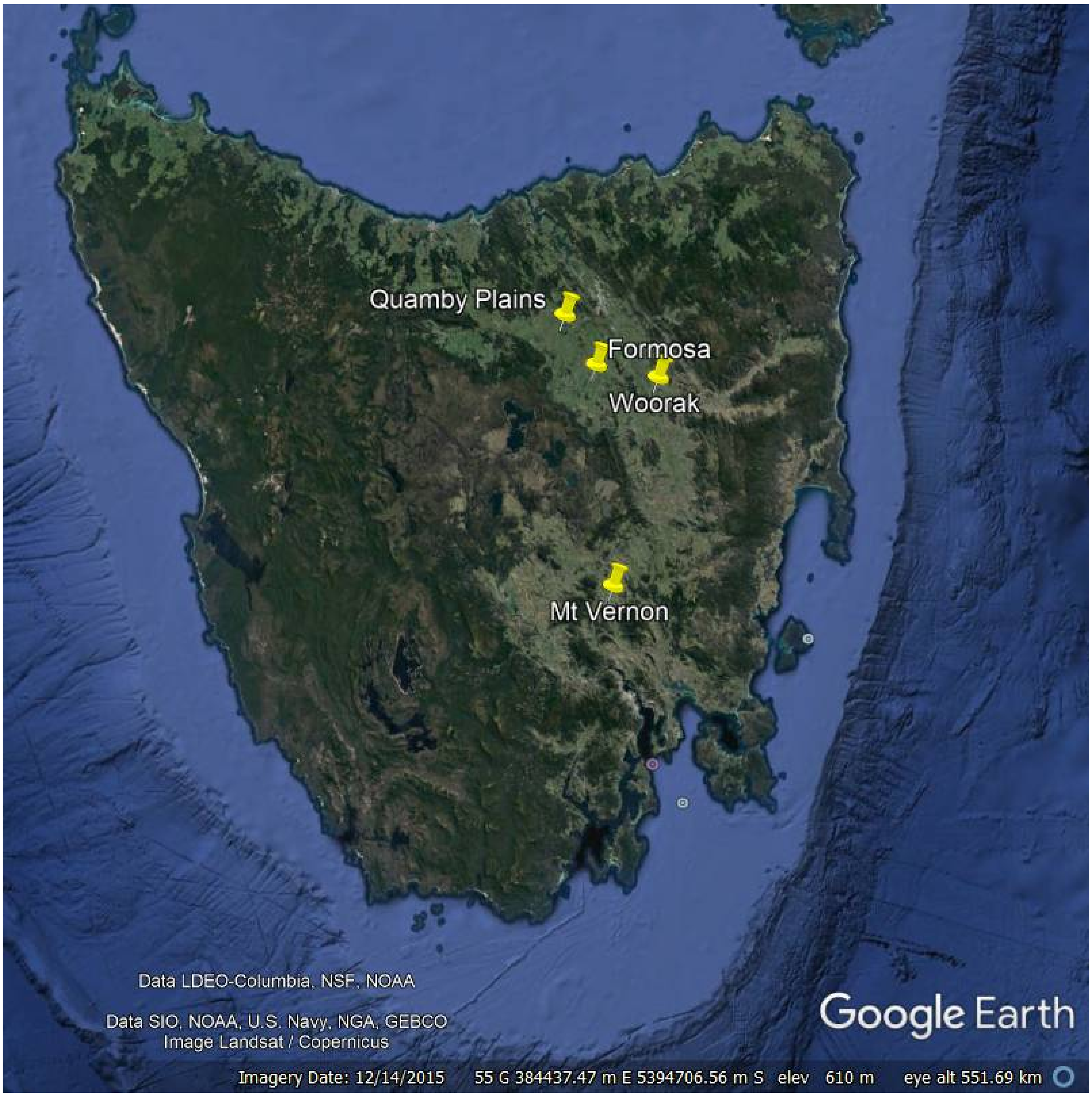
2.1 Case study sites

The four sites used in this study were those that have been studied as part of an agroforestry project that has been delivered by Private Forests Tasmania, The University of Tasmania, and CSIRO (see Fig. 1 for locations). These sites have had various levels of monitoring, including pasture production measurements, micrometeorology (wind, temperature and humidity) and soil moisture. All sites were selected such that they had an established *Pinus radiata* shelter belt on the windward side (western edge), averaging around 15 to 20 m in height. The Formosa site, near Cressy, had been the flagship site for the project, as the pasture had been established by the landowner across the whole paddock at the start of the project, and the greatest number of measurements have been made at that site. It is climatically representative of the northern midlands of Tasmania. The Quamby Plains site, near Carrick, has higher rainfall, and is more productive, while the Woorak site has lower rainfall, and is generally representative of the lower productivity sites in the northern midlands of Tasmania. The fourth site, on the Mt Vernon property is in southern Tasmania, and is representative of many areas in the southern midlands that could benefit from expansion of agroforestry systems. Key characteristics of each of the sites is shown in Table 1 (Data from England et al, 2018).

Table 1 – Key characteristics of the existing shelter belts at each of the 4 sites

	Formosa	Quamby Plains	Woorak	Mt Vernon
Location	Cressy	Carrick	Epping Forest	Kempton
Tree height (m)	15.3	18.8	15.4	14.6
Shelter belt age (y)	15	18	31	21
Tree rows	5	3	2	7
Standing volume(m^3/ha) of:				
Edge rows	337.6	558.9	522.7	412.6
Inner rows	207.1	394.3	247.5	299.2

Fig. 1 – Locations of the four case study sites

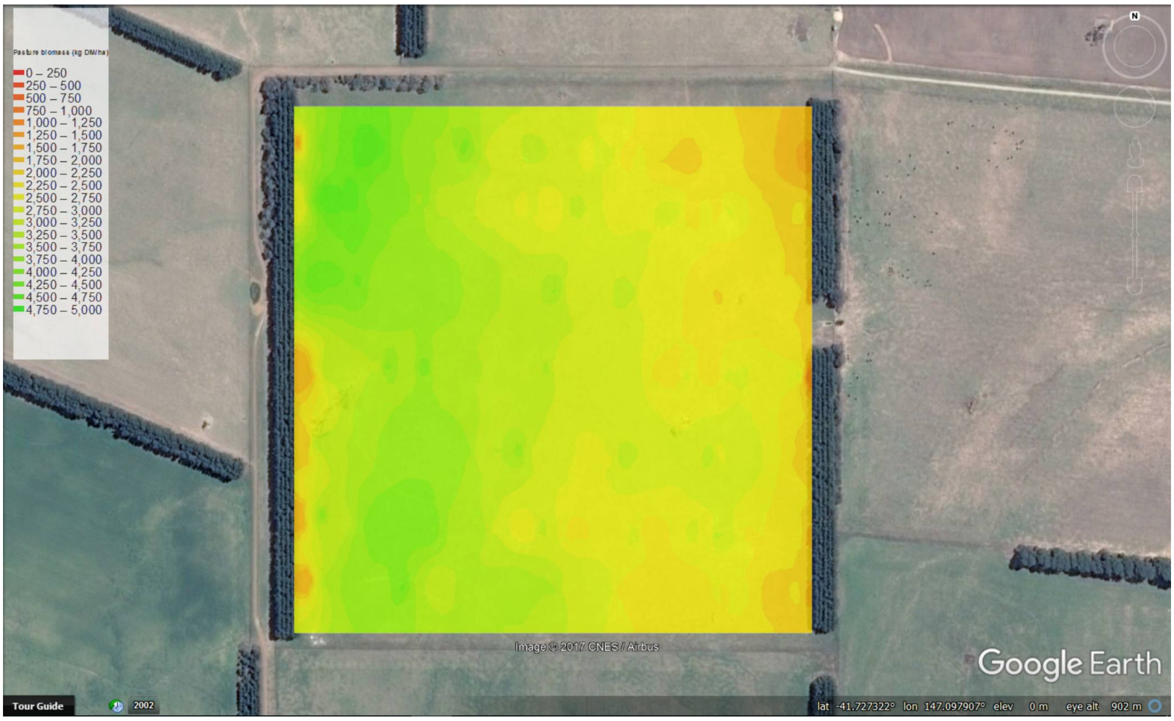


2.2 Shelter benefits

Substantial effort has been placed on understanding the benefits and costs that shelter has on producing pasture biomass. It is evident that there is a major benefit of the shelter on pasture production, with a key whole-paddock measure at the Formosa site in October 2017 demonstrating that the sheltered half of a 25 ha paddock produced around 30% more pasture biomass than the unsheltered half of the paddock. Figure 2 shows a map of the pasture production measured across the paddock at Formosa. Pasture exclusion cages were installed at the 3 sites in the northern midlands, but they proved unreliable in generating sufficient quality data for use in the modelling. The exclusion cages suggested that there was a shelter benefit on pasture production at all sites, but currently the most reliable source of information is the one-off pasture probe measurement at Formosa in October 2017, because of the spatial intensity of measurements that this methodology allows. At this measure, a pasture biomass probe (Grassmaster Pro, https://www.novel.co.nz/product/356250?nav=ccy) was used to assess the pasture biomass in detail along 7 transects away from the tree rows. The biomass was assessed every 10 m along each transect, from the trees across to the other side of the paddock. The pasture probe was calibrated to the site by cutting, drying and weighing the pasture biomass at 7 points with pasture biomass ranging from 500 to 3800 kg DM/ha. A pasture probe measurement was taken before and after cutting, and a relationship determined between the biomass removed and the difference in pasture probe capacitance readings. The R^2 for the correlation was 95%.

In addition to the benefits of shelter on pasture biomass production, previous studies have reported the impact of shelter on reducing livestock mortality Baker et al. (2018), but there are only a few available experimentally-derived quantitative data to allow us to accurately predict this. Baker et al. (2018) compiled the available data, which was used to develop the methodology for inclusion in Imagine, and to provide the best available estimates to inform these assumptions. These assumptions are inputs to the model, and can be updated as new information becomes available in the future.

Fig. 2 – Map of pasture biomass in October 2017, after 7 weeks of stock exclusion. The western half of the paddock had 30% more pasture biomass than the eastern half of the paddock.



2.3 The Imagine model

The Imagine model was developed by Amir Abadi and Quenten Thomas, through the CRC for Future Farm Industries. It was designed to model the bioeconomics of mallee agroforestry systems in Western Australia. Imagine has sufficient flexibility to allow for a range of scenarios of cropping, pasture and trees, such that we were able to adapt it for use in agroforestry systems in Tasmania. In the implementation of Imagine for this study, it employs empirical relationships or productivity functions to predict the growth of pasture in relation to rainfall, while we used a combination of empirical (measured) and CABALA predicted productivity and height growth to provide Imagine with the tree growth and returns.

Imagine runs on a sub-monthly timestep, and allows for the costs and returns from user-specified operations to be accounted for in predicting the overall economics of the system. It operates at the paddock scale, and has the capacity to incorporate as many belts of trees as the user wishes.

Livestock production is modelled in Imagine as a self-replacing flock of sheep, with outputs of both wool and meat. The food on offer (FOO) for livestock (from pasture growth) is calculated based on monthly rainfall, and an empirical relationship between the rainfall and pasture production of any given month, taken from the Meat and Livestock Australia website (http://mbfp.mla.com.au/Pasture-utilisation/Tool-33-Pasture-growth-estimates/Tool-33-Tasmania-feed-year-growth-rate-patterns, accessed 4/12/2018). Pasture growth responses to rainfall at the Cressy Research Station were used at the Formosa and Quamby Plains sites, while measurements from the Bureau of Meteorology station at Melton Mowbray were used at the Mt Vernon site. The Woorak site was considered to be mid-way between the Cressy and Melton Mowbray pasture production rates. The pasture production model assumes a fixed stocking rate (dry sheep equivalent, DSE/ha), and utilises the pasture FOO down to a given lower limit (in this case, we used a cutoff of 1100 kg dry matter, DM/ha). Once this lower limit is reached, the livestock are fed by the model with grain. Note that the assumption of a fixed stocking rate means that the model predicts only minimal changes in outputs of meat and wool (driven by reduced mortality), but costs increase when there is a FOO shortfall that needs to be supplemented by hand feeding.

The newly developed version of Imagine now has the capacity to model the amenity, shelter, and carbon sequestration, as well as timber production. The methodology to apply each of these factors in the updated Imagine model include:

- Amenity values are taken from the study of Polyakov et al. (2014), who demonstrated that trees on farms tended to increase the land value by at least 10%. We assumed a 10% increase in land value, incremented over 5 years, and assuming a land value of $10,000/ha.
- Carbon sequestration was modelled according to the Carbon Farming Initiative – Plantation Forestry methodology (http://www.environment.gov.au/climate-change/government/emissions-reduction-fund/methods/plantation-forestry) which assumes that the plantation land use sequesters on average around half of the total carbon increase, moving from a low-carbon land use baseline to a higher standing carbon biomass. Half of the total amount is used because it assumes that the system is harvested and on average, the total amount of C sequestered will be half of the end-rotation amount. The methodology allows for the increase in total C to be paid annually for the first 15 years of the project life.
- Timber production was taken from the measured productivity at each site, accounting for the differences between edge rows and inner rows (England et al., 2018). For example, a 2-row belt was assumed to have the same productivity as full edge rows, while a 10-row belt was assumed to have the productivity equivalent to 2 edge rows and 8 inner rows. Edge rows typically had much higher productivity (40-110% higher, see Table 1), which had a substantial impact on the predicted productivity of the different belt configurations.
- The shelter benefits of the trees on pasture production was taken from the October 2017 measure at Formosa, but for the purposes of the model, it was assumed that the magnitude of the shelter impact on productivity remained proportionally the same in every month (so when pasture growth is lower, the effect is also lower), but that the pasture benefit was only 60% of that measured at Formosa. The impacts of this assumption were tested in the sensitivity analysis. The shelter effect is measured in tree heights, with no shelter effect beyond 20 tree heights, so the sheltered area increases as the trees grow.

2.3.1 Key Assumptions used in the modelling

Key input costs for the pasture production were taken from the 'Low rainfall Livestock Enterprise Margins, April 2017' spreadsheets, produced by the Department of Primary Industries, Parks, Water and Environment, Tasmania (available at: http://dpipwe.tas.gov.au/agriculture/investing-in-irrigation/farm-business-planning-tools, accessed 5/12/2018). From these spreadsheets, pasture maintenance costs (fertilizer, spraying, renovation etc.) of $86/ha/year were assumed, as well as sheep rearing costs of $13.50/head/year, inclusive of shearing, crutching, and animal health, but exclusive of interest on stock. Feed costs of $300/tonne were used in the model. For modelling purposes, a stocking rate of 18 DSE/ha was assumed. Assumed prices for wool and meat are shown in Fig. 3.

Fig. 3 – Key inputs used for wool sales, sheep sales, fodder quantities and FOO settings used in the Imagine modelling scenarios. Note that different condition scores (CS) were not differentiated in this study, so they were given the same sales values. Units are per head (hd) of sheep of different categories, or per hectare of area. Cast For Age (CFA) ewes, rams, and wethers are sheep to be culled because of their age.

ShelteredPastureGrowthModelDialog

Wool Sales Mar

	# / 1000 ewes	kg / Hd	$ / kg (nominal)
Ewes	960	5.4000	16
Ewe Hoggets	208	5.4000	18
Ewe Lambs	425	1.1000	16
Rams	20	8	16
Wethers	0	5.4000	16
Wether Hoggets	0	5.4000	18
Wether Lambs	425	1.1000	16

Sheep Sales Sep

	# / 1000 ewes	$ / Hd (nominal) CS 2	$ / Hd (nominal) CS 3
CFA Ewes	177	91	91
Ewe Hoggets	196	119	119
Ewe Lambs	0	119	119
CFA Rams	4	85	85
CFA Wethers	0	85	85
Wether Hoggets	0	119	119
Wether Lambs	421	85	85

Fodder Costs

	kg / Hd / week
per Ewe	6
per Ewe Hogget	6
per Ewe Lamb	3.5000
per Ram	3
per Wether	5
per Wether Hogget	5
per Wether Lamb	3.5000

FOO Settings

	FOO (kg / Ha)
Available in Start month	1500
Required to permit grazing	1100
Required for CS > 2	1500
Above which CS = 3	12000

Month Jan

Shelter Benefits Settings File (*.m) getFormosaSettings.m Select

DSE Conversion: 2500 DSE / 1000 ewes

Cancel Ok

Key assumptions used in the tree production module included a stumpage value for the final product of $40/m^3, harvesting at 25 years, with a thinning operation removing around 20% of the standing biomass at age 15. The thinning stumpage was assumed to be $25/m^3. Carbon credits were assumed to be worth $7.00/tonne of CO_2 equivalent (compared to price of $11.97 paid through the first seven auctions of the Emissions Reduction Fund, http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/june-2018). This assumes that around $5 would be paid to an aggregator. Expansion factors (to convert stem volumes to above-ground biomass) were sourced from Snowdon et al. (2000).

Establishment costs for the trees were assumed to include fencing ($7/m), per seedling costs at planting of ($1.80), site preparation costs of $275/ha, and post plant weed control of $100/ha.

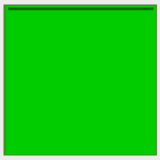
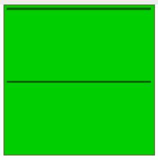
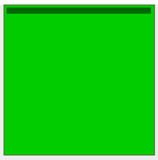
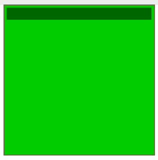
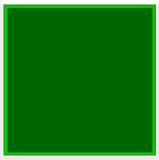
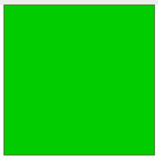
The calculation of the shelter on pasture production assumed that the observed shelter effect was 60% of that observed at Formosa in October 2017, and proportional to the predicted pasture productivity in any given month. The shelter effect of trees on livestock mortality was assumed to be related to tree height, such that there was no effect until the trees reached at least 3 m tall, and that the maximum benefit was obtained when trees were 20 m tall or more. A linear relationship was assumed between 3 and 20 m, such that up to 50% of the mortality could be reduced, assuming annual mortality rates of (per 1000 ewes): 32 ewes, 12 ewe hoggets, and 120 lambs. The implication is that when the trees were 20 m tall or higher, mortality would have been reduced by 16 ewes, 6 ewe hoggets and 60 lambs per 1000 ewes.

For the purposes of comparison and analysis in the modelling, paddock sizes of 500 m x 500 m were assumed at each of the sites, though this was the actual paddock size only at Formosa.

2.3.2 Scenarios

The range of scenarios were explored at each of the four sites are shown in Table 2. Tree rows were assumed to be 3.9 m apart, with 2.7 m spacing between seedlings within the rows. Belts were given a 10 m buffer at each end, such that they were 480 m along the windward edge of the 500 m simulated paddock

Table 2 – Belt/row scenarios used in Imagine modelling

Description	Schematic
2-row shelter belt on prevailing windward side of the paddock. Trees occupy 0.37 ha, pasture occupies 24.63 ha	
2 x 2-row shelter belts, with one row on the prevailing windward edge, and one parallel to this in the middle of the paddock. Trees occupy 0.75 ha, pasture occupies 24.25 ha	
5-row shelter belt on the windward edge of the paddock. Trees occupy 0.93 ha, pasture occupies 24.07 ha	
10-row shelter belt on the windward edge of the belt. Trees occupy 1.87 ha, pasture occupies 23.13 ha	
Full trees	
Full pasture	

The net benefit of the trees was calculated as the difference between the scenarios with trees, and the full pasture scenario.

2.3.3 Sensitivity analysis

To understand the uncertainties surrounding some of the input factors, sensitivity analysis was conducted on the stocking rate (from 8 to 20 DSE/ha), the shelter effect on pasture production (from zero to 100% of that observed at Formosa), and wood prices (of \$0, \$5, \$10, \$20, \$40, and \$80/m^3). A base case of the 2-row belt configuration at Formosa was used in all of the scenario analyses, and the input variables were modified around the other parameters. Given the similarities in responses between sites, the Formosa case study serves as a good indication of the trends likely to occur at each of the sites.

3 Results and Discussion

3.1 Gross margins

The average gross margins over the 25-year rotation were always lowest for the full-tree scenario, and highest for the system with integrated 2-row belts (Fig. 4). Inclusion of wider tree belts did not improve the economic returns at any of the four sites. When all products were included (Fig. 4), the net benefit of 2 rows of trees (across the whole 25 ha paddock), compared to full pasture equated to between $41.39/ha/y and $74.05/ha/y across the 4 case study sites (Table 3). When the benefits of the trees were attributed to the area under trees, the equivalent gross margins (on a per hectare basis) were substantial (Fig. 5), with the net attributed value for the 2-row belt of trees between $3,965/ha/y at Mt Vernon, and $6,194/ha/y at Quamby Plains (Table 3).

Table 3 – Predicted net benefit of a 2-row tree belt across the whole paddock, and if attributed only to the area under trees.

Site	Net benefit (gross margin) across whole paddock ($/ha/y)	Attributed gross margin to tree area ($/ha/y)
Formosa	$60.19	$5,041
Mt Vernon	$41.39	$3,965
Quamby Plains	$74.05	$6,194
Woorak	$68.31	$5,576

Fig. 4 –Average gross margins across the 25 year rotation at all sites, all products included (meat, wool, amenity, carbon, and timber)

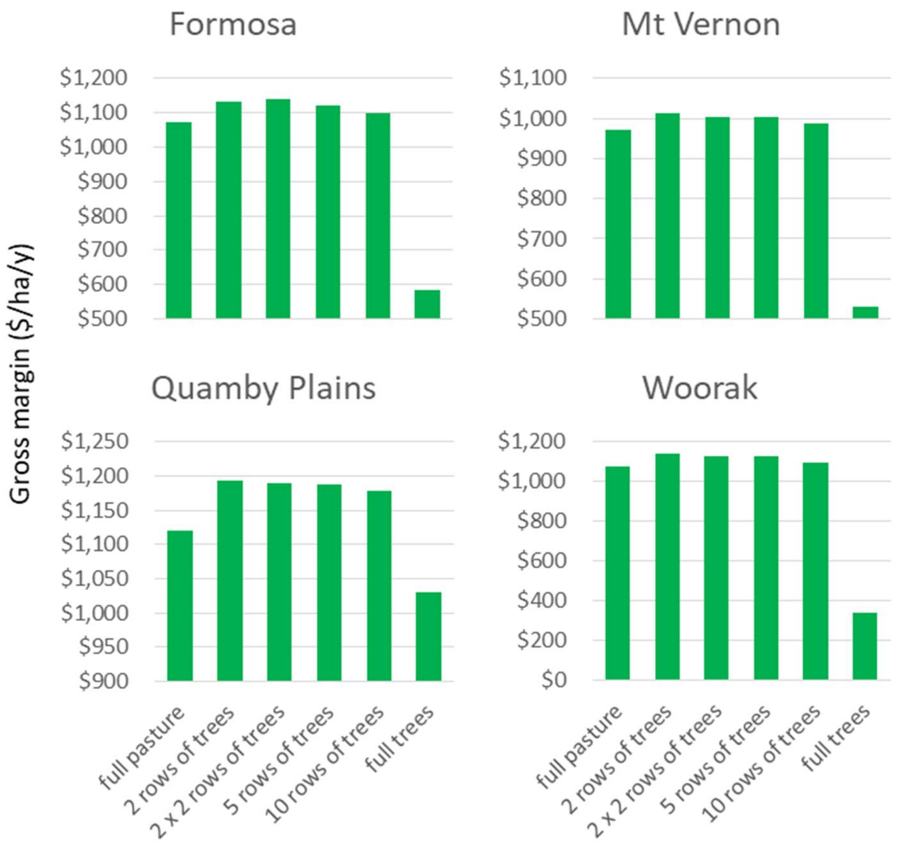
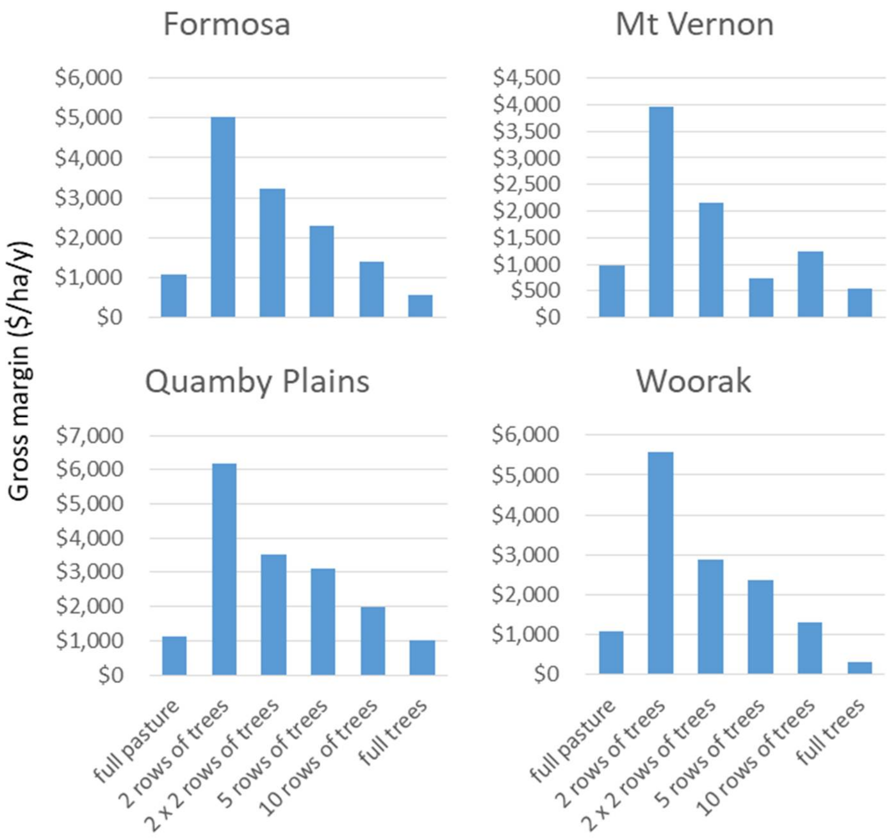
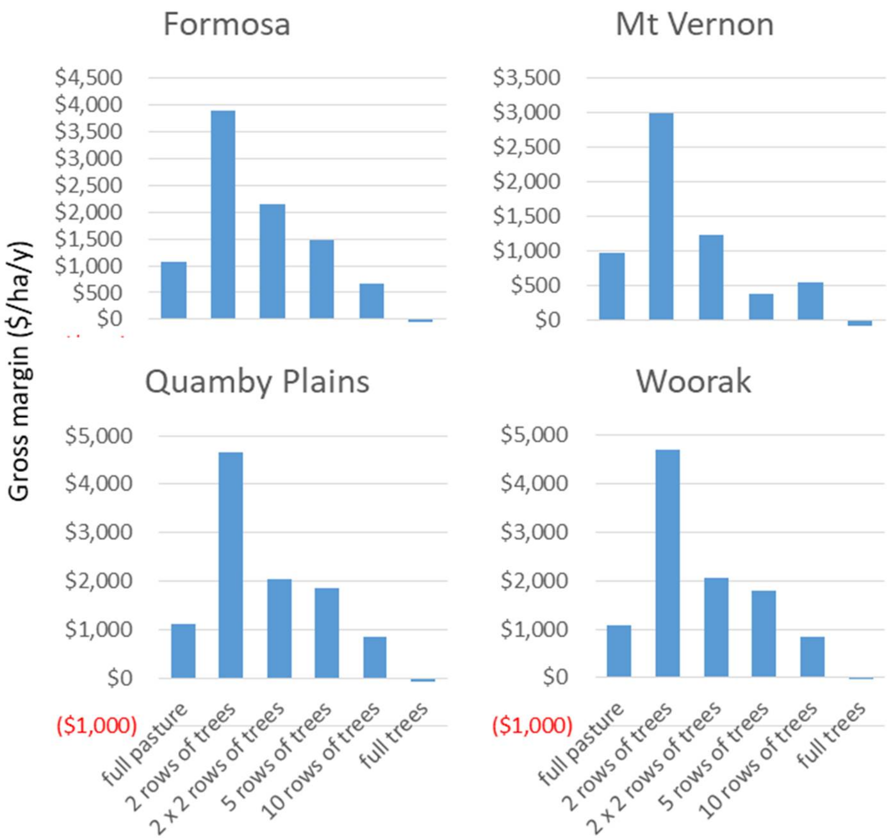


Fig. 5 – Equivalent average gross margin ($/ha/y) for pasture or tree belts across the four sites. This assumes that the net benefits that the trees convey to the pasture are allocated to the tree belt area.



If the carbon and amenity values were excluded from the calculations, gross margin attributed to the area under a 2-row belt was reduced to $4,764, $3,707, $5,847, and $5,342/ha/y for Formosa, Mt Vernon, Quamby Plains and Woorak, respectively, with these values only contributing the equivalent of $200-$300/ha/y. Even if the tree crop was assumed to provide no returns of its own (with the only return being from the shelter benefit to agriculture), the returns per hectare of shelter belt were still higher than for the full pasture alone for almost all the scenarios (Fig. 6), except the wider belts at Mt Vernon.

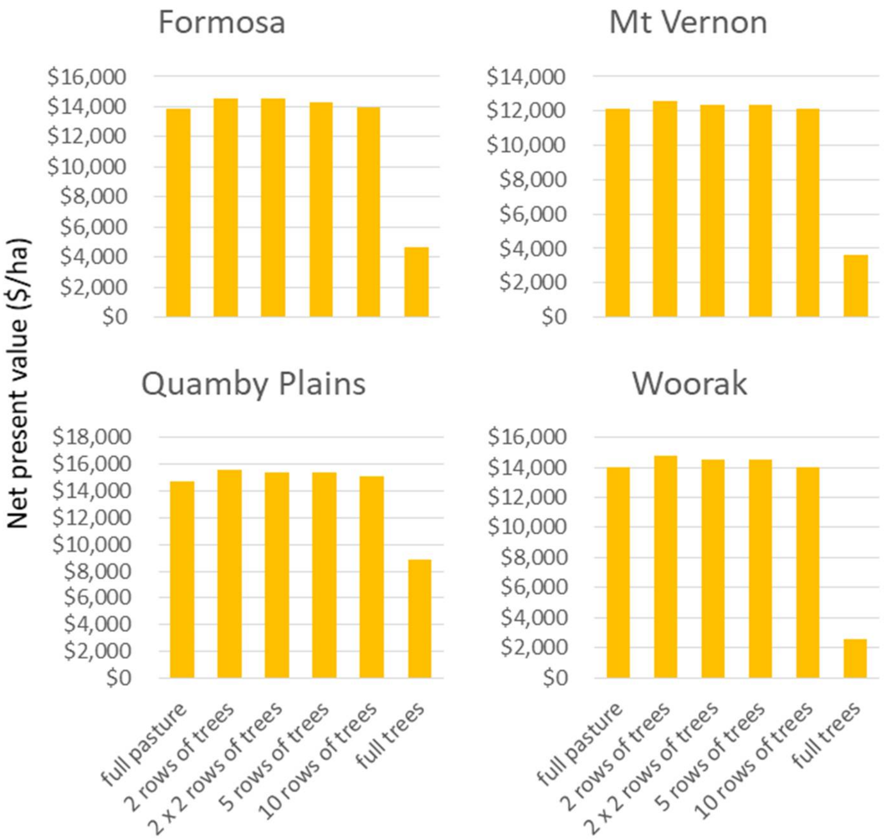
Fig. 6 – Average gross margin of crop system ($/ha/y), assuming only returns from the shelter (no returns for the timber, amenity or carbon).



3.2 Net Present Values

Recognising that the gains from the trees increase over time, and the value of money needs to be accounted for, the net present values for the investment (assuming a discount rate of 5%) still demonstrated that the agroforestry configurations gave higher returns than the pasture alone, and much higher than the full trees scenarios at each of the sites (Fig. 7).

Fig. 7 – Net present values of the different agroforestry configurations, with all products included.



3.3 Income sources from trees over time

The annual (Fig. 8) and cumulative (Fig. 9) returns from the trees demonstrate the relative importance of each of the income streams under the model scenarios, with additional income from the agricultural land use far more important than the returns from the tree-only benefits. The values of amenity and carbon sequestration are relatively minor compared to the overall returns. The scenario presented in these figures is based on a 2-row system at Formosa, which only occupies ~0.4 ha of the 25 ha paddock. Increasing the numbers of rows does substantially increase the final returns at harvest of the trees, and the trees still convey a positive return to the landowner, but the modelling suggests that the additional returns do not outweigh the additional opportunity costs compared to a 2-row system.

Fig. 8 – Calculated annual returns from each of the sources of income from the trees in a 2-row configuration at Formosa. Livestock income is additional to the base case pasture-only scenario. Note that dry years at 11, 14 and 17 had lower livestock returns because of higher feed costs.

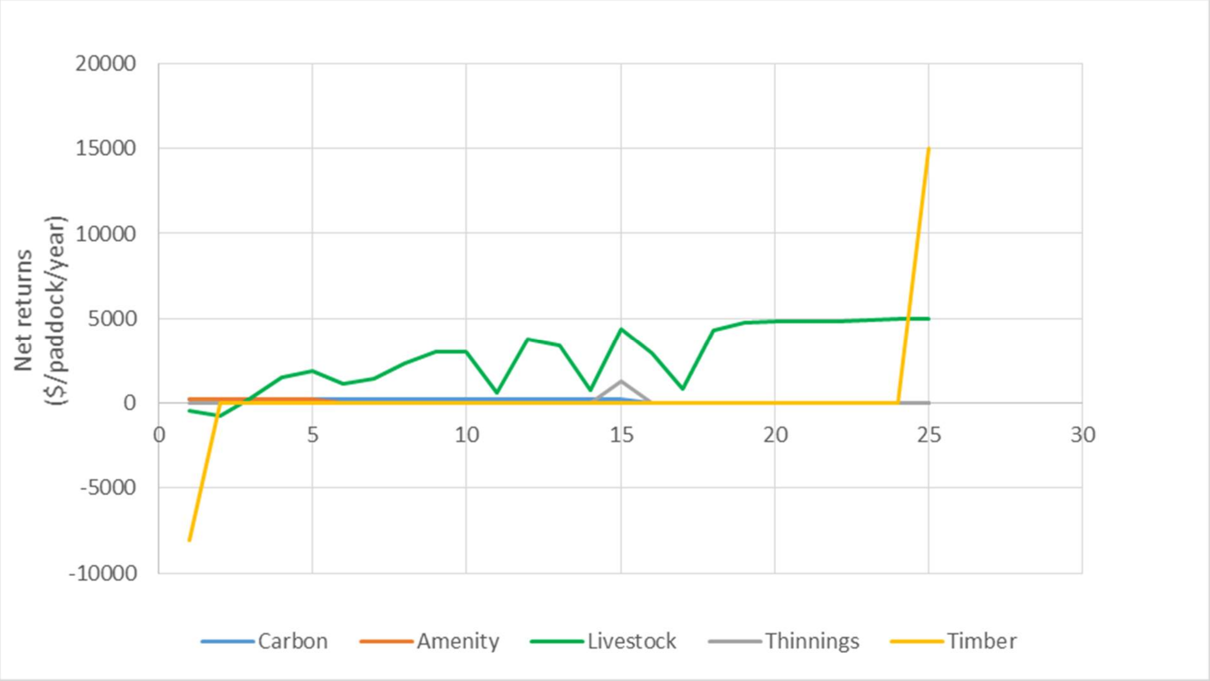
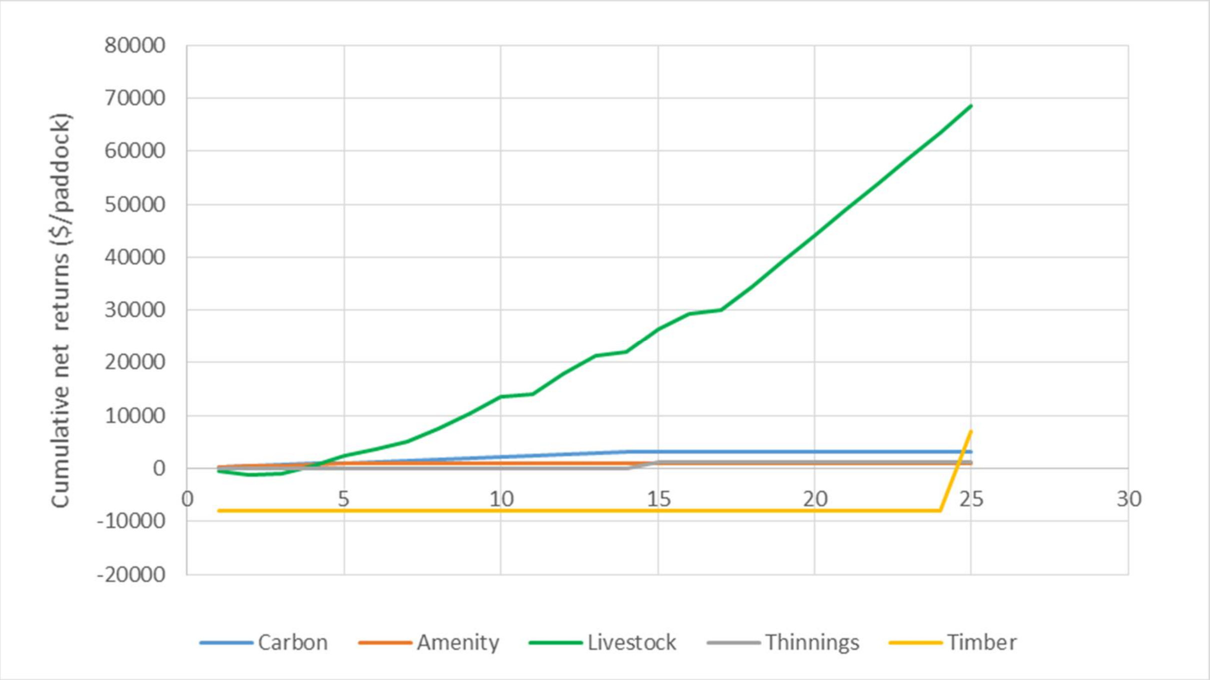


Fig. 9 – Cumulative returns from each of the tree income sources.



3.4 Comparing annual returns

Annual gross margins from each of the revenue streams is shown in Table 4, demonstrating that the most profitable configuration of those explored was the 2-row belt, or the 2 x 2 row belt. The increased livestock profitability represents around 90% of the total benefit in a 2-row configuration, and only around 42% of the benefit in a 10-row belt configuration.

Table 4 – Calculated annual gross margin ($/paddock/year) from different sources with variable configurations of tree belts at Formosa (averaged over the 25 year simulation). Note that this analysis is not discounted.

Revenue source	2-row belt	5-row belt	10-row belt	2 x 2-row belt
Carbon	$64.80	$123.60	$223.20	$130.20
Amenity	$40.00	$40.00	$40.00	$40.00
Livestock	$2,205.08	$1,680.28	$809.36	$2,740.64
Timber	$164.44	$418.52	$844.44	$328.80
Total	$2,474.32	$2,262.40	$1,917.00	$3,239.64

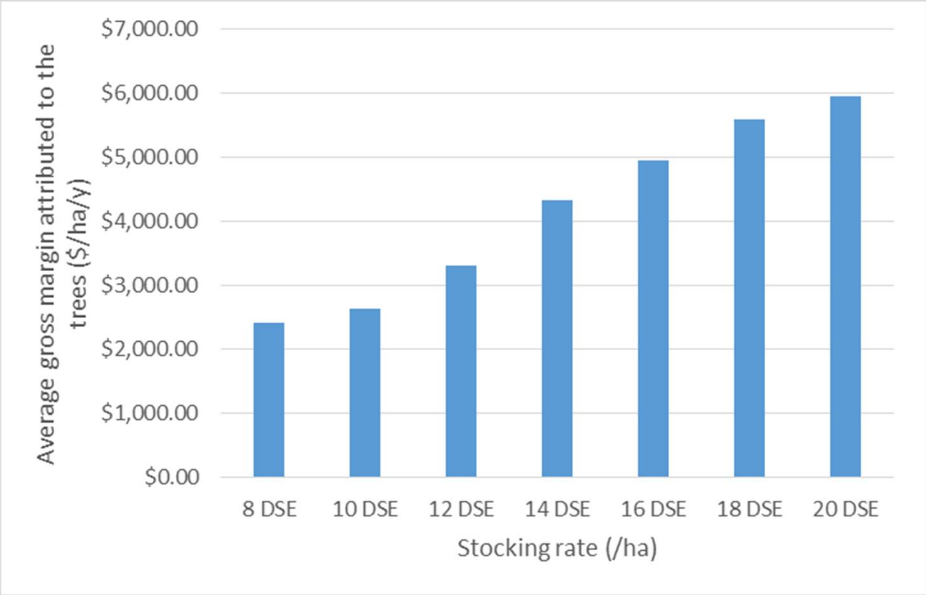
3.5 Sensitivity analyses

3.5.1 Stocking rates

The benefits of additional pasture growth can only be accrued if the stocking rate of the pasture is sufficient to utilise it. Thus, at lower stocking rates, the hand-feeding costs are similar between the tree and pasture-only scenarios, and the benefits of trees increase as the stocking rate increases (Fig. 10). However, trees always increased the whole-paddock gross margin under these scenarios, from $25.60/ha at 8 DSE/ha to $74.48/ha with 20 DSE. This still translated to gross margins under the trees equivalent to $2,403/ha at a stocking of 8 DSE/ha, to $5,958/ha at 20 DSE/ha (Fig. 11).

Fig. 10 – Impact of stocking rate on average gross margin from the pasture only (blue bars), and pasture with 2 rows of trees (orange bars) at the Formosa site. This scenario assumed that all products from the trees were included (carbon, amenity, additional meat and wool, and timber).

Fig. 11 – Average gross margin attributable to the area under trees with different stocking rates. Assuming all products are included.



3.5.2 Shelter effects on pasture production

Given the uncertainty around the impacts of shelter on both pasture production and livestock mortality, scenario analyses were conducted around these variables. The proportional benefit of shelter on pasture was explored by increasing the proportional benefit observed at Formosa from zero to 100%, both with and without the shelter benefits for reducing mortality. Including the reduced livestock mortality effect of the shelter belt always increased the average gross margins above the full pasture base case (Fig. 12). If the shelter effect on reducing mortality was not included (orange bars in Fig. 12), the effect of trees on the paddock level gross margin was also higher than the base case of full pasture if all products were included (Fig. 12). However, if no value was attributed to any of the tree products (Fig. 13), then the average gross margins were lower than in the full-pasture case only until the effect was at least around 50% of that observed at Formosa in October 2017.

Fig. 12 – Impacts of shelter effect on average gross margin, with or without the effect of shelter reducing livestock mortality. Note that 100% shelter effect is equivalent to the benefit on the trees measured on the pasture at Formosa in October 2017. All products are included

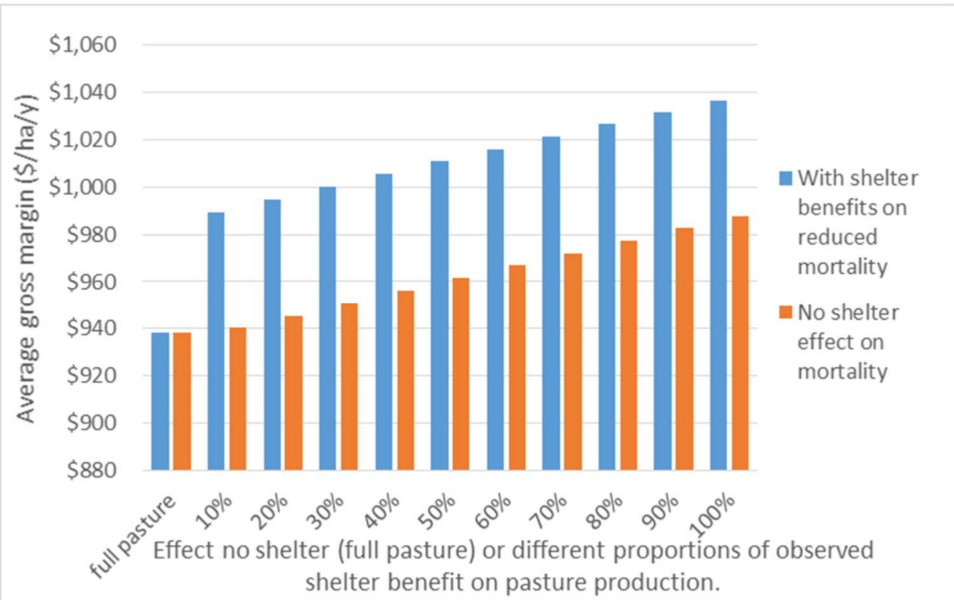
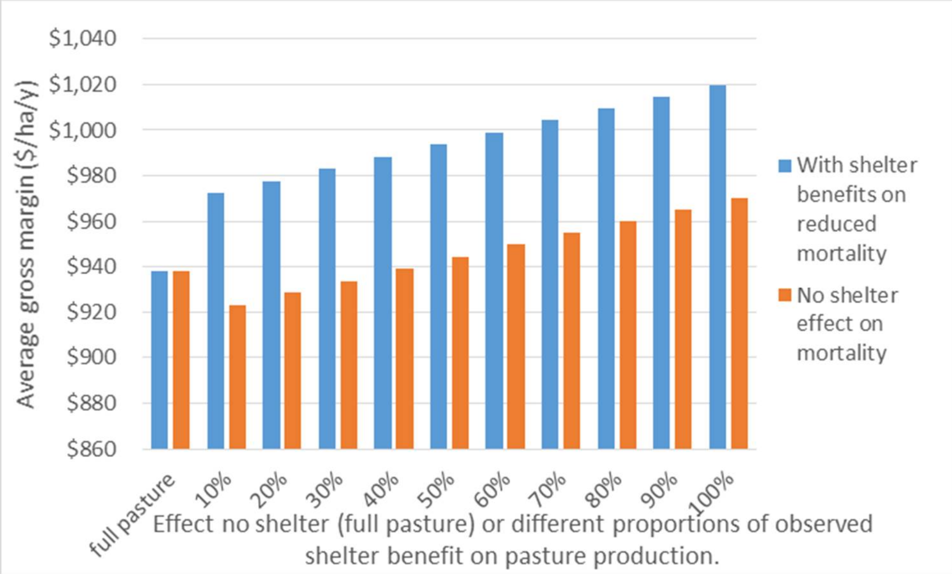


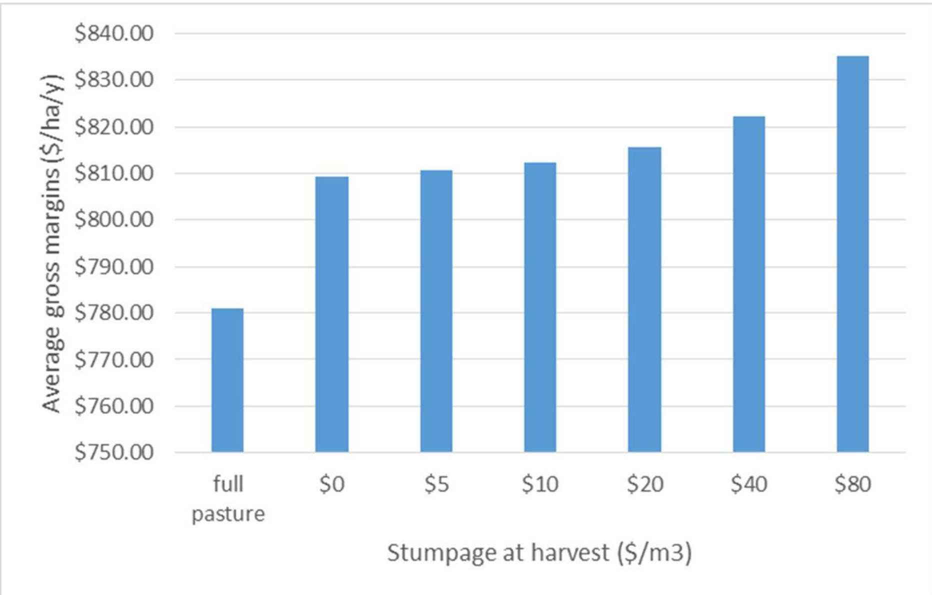
Fig. 13 – Impacts of shelter effect on average gross margin (as per Fig. 12), but with no value attributed to any of the tree products



3.5.3 Wood prices

The stumpage rates for timber are variable and cyclical, and so we explored the impact that the price of wood had on returns. The net benefits of an agroforestry system were higher than for pasture only in all cases, even when the wood had a $0 value (Fig. 14), as most of the benefits accrued via the improvements to the agricultural returns. Even high stumpage rates of $80/m^3 only increased the paddock-level returns by less than $30/ha, or by less than the difference between the pasture-only, and trees with $0 return at harvest scenarios.

Fig. 14 – Sensitivity analysis around average gross margins for full pasture and different stumpage values at harvest



4 Conclusions

This study has demonstrated that integration of agroforestry belts into pasture systems in Tasmania is likely to provide a positive return, both at the whole-paddock scale, and especially when the benefits are considered to accrue to the area under trees. These returns are quite robust because they are derived from a number of sources in addition to the timber values at harvest. These results also suggest that the traditional paradigm that agroforestry is better suited to land uses with low opportunity cost may be inaccurate, as most of the returns come from the benefits that the trees convey to the adjacent agriculture, rather than from the trees themselves. Further work is warranted in understanding the costs and benefits of establishing agroforestry systems on agricultural land with higher opportunity costs. Further work is also warranted in deepening our understanding of the biophysical effects of shelter on pasture (and crop) production, as the shelter benefits used in this modelling analysis are based on a very limited sampling in space and time. Whole-paddock establishment and assessment provides a much richer picture of the shelter impacts on productivity, and needs to be repeated in other situations and scenarios. Livestock mortality should also be quantified in more detail because it has a significant impact on the economics of the system. While 2-row belts are the most attractive under all scenarios in this study, it should be recognised that this analysis does not account for economies-of-scale in harvesting, and that lower stumpage rates may be achieved, and/or harvesting contractors may be difficult to obtain if there is insufficient scale of resource to make it worth their while to harvest. Thus, it is recommended that wider belts may be a better solution if they allow for sufficient resource to be developed to facilitate end-rotation harvesting. Local knowledge of markets, harvesting contractors and productivity is needed to ensure that the scale of the resource is sufficient to allow the timber to be harvested profitably.

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