Article

Case Studies of the Financial Performance of Silvopastoral Systems in Southern Queensland, Australia

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Abstract: There is considerable uncertainty surrounding the future availability of hardwood timber from state-owned native forests in southern Queensland. The timber industry is becoming increasingly reliant on private native forests, where much is on properties primarily managed for beef cattle grazing. Historically, these forests have been periodically high-grade harvested without silvicultural treatment or cleared to increase pasture production where landholders have the right to do so. This study compares these traditional forest management practices at four case study properties against silvopastoral system alternatives. Merchantable timber, pasture and cattle production was estimated for each management scenario with a native forest silvicultural treatment response model. The net present value of each scenario was estimated over a 20-year management period. For all case study properties, the worst-performing forest management scenario was to clear forest for grazing. Investment in silvopastoral systems in southern Queensland was found to be financially attractive, particularly when silvicultural treatments were implemented in year zero to increase timber production. Silvicultural treatments increased the mean annual increment of merchantable timber over 20 years by an average of 1.3 m^3/ha/year relative to the scenario where no management was performed in year zero. Forest management scenarios with silvicultural treatments had better financial performance than scenarios without silvicultural treatment. However, long payback periods and sovereign risk are serious impediments to silvopastoral system adoption in southern Queensland. If these concerns can be overcome, private native forests have the potential to be sustainably managed to improve the financial performance of farms, improve regional employment and income generation, supply Queensland's future hardwood timber needs, and increase carbon sequestration and biodiversity conservation on private land.

Keywords: livestock; agroforestry; timber production; forest management; silvicultural treatment; pasture

1. Introduction

Silvopastoral systems, which combine natural forests or planted trees with pasture and livestock on the same land management unit, have gained popularity internationally in recent years as an environmentally friendly and economically viable land use [1–4]. This popularity has come as agriculture is facing intense pressure globally to increase productivity while having greater environmental accountability [3]. Silvopastoral systems are not homogeneous, and there are many ways forestry and livestock production may be integrated [5]. Along with the environmental benefits such as aesthetics, water quality improvement, soil conservation, carbon sequestration, and wildlife habitat conservation [6], silvopastoral systems have the potential to be financially beneficial to private landholders by increasing the resilience of farms to climate change, ameliorating the annual cash flow

problems inherent in timber growing, diversifying farm incomes and promoting multiple-use management [7,8].

Literature on the financial performance of hardwood silvopastoral systems is scarce, both in Australia [9] and internationally [10,11]. Multiple international studies of softwood silvopastoral systems have found that net present values (NPVs) are consistently higher than both timber alone and grazing alone [12–14]. Dube et al. [15] compared the financial performance of a eucalypt-based agroforestry system against eucalypt plantations in the savanna region of Brazil. They found that silvopasture was financially optimal over the eucalypt plantation, with land expectation values of USD 560.10/ha and USD 57.33/ha, respectively. In Amazonas, Peru, Chizmar et al. [16] modelled the financial returns from silvopasture plantation forests of *Eucalyptus globulus*, *Alnus acuminate* and *Pinus patula*, and conventional cattle-pasture systems. They found that silvopastoral systems with cattle and *E. globulus*, *A. acuminate* and *P. patula* returned the highest NPV (USD 5951/ha), compared to timber only from a *P. patula* forest (USD 527.87/ha) or grazing only (USD 796/ha). Orefice et al. [11] assessed the profitability of open grazed pasture, silvopasture (grazed thinned woodland), and thinned woodland for timber production only (i.e., grazing excluded) in an early successional northern hardwood forest in New York, United States. The site's history included charcoal production and dairy grazing; however, in the 1960s, use of the site ceased and it gradually reverted back to forest [11]. They found that the silvopastoral treatment was financially optimal over a 30-year management horizon, with an NPV of USD 1277/ha at a discount rate of 3%.

In southern Queensland, Australia, Schulke [17] estimated the financial performance of forested land that was: (a) cleared for grazing; (b) periodically high-grade harvested; and (c) grazed, silviculturally treated and managed for timber and cattle. High-grading involves the harvesting of commercially valuable trees while leaving unmerchantable and damaged trees standing. Using data from Schulke [17], Venn [9] estimated the NPVs of grazing on cleared land, periodically high-grade harvested forest and silviculturally treated forest with grazing at a discount rate of 5% to be AUD 540/ha, AUD 200/ha and AUD 750/ha, respectively (in December 2021, AUD 1 wasUSD 0.73). Donaghy et al. [18] developed a bioeconomic model to examine several silvopastoral system scenarios in poplar box and brigalow woodland in the Fitzroy Basin of central Queensland, including regrowth (natural regeneration) strip retention and plantation spotted gum strips. In that study, there appeared to be large potential benefits from spotted gum plantation strips, with the NPV of this silvopastoral system being AUD 210/ha greater than cleared grazing land. Maraseni et al. [19] estimated the returns to a silvopastoral system with plantation spotted gum on a property near Kingaroy in southeast Queensland. In that study, at 31 years and a discount rate of 6%, the grazing component of the silvopastoral system had an NPV of AUD 779/ha and the timber AUD 2099/ha, for a total of AUD 2878/ha.

Forest management and processing of logs from subtropical eastern Australian forests have sustained employment and income generation opportunities in many regional communities for generations [20,21]. However, there has been increased scrutiny of public forest management, which has resulted in substantial declines in timber supplied from state-owned native forests [22]. The hardwood timber industry has become increasingly dependent on private native forests to maintain log supply. The reliance on private forests in Queensland is likely to increase in the next decade as long-term wood supply agreements from state-owned forests end [23]. As part of the Native Timber Action Plan, state-owned native timber production will end in the South East Queensland (SEQ) Regional Plan area on 31 December 2024, with uncertainty surrounding the remainder of the SEQ supply region [24].

After accounting for regulatory restrictions, there are approximately 2.1 M ha of potentially harvestable private native forest in southern Queensland [25]. Much of this resource is on properties where the primary economic activity is cattle grazing. Although large in area, the forests are generally in poor productive condition due to decades of 'high-grading' without follow-up silvicultural treatment [21,26]. Over time, high-grading

can lead to locked-up stands with low merchantable growth rates that are dominated by non-merchantable trees in the canopy and a high density of small stems that are suppressed under the canopy [27]. Locked-up stands can also arise from even-aged regeneration on previously cleared land where there is severe competition for site resources in the absence of thinning or natural disturbance to free up growing space.

Part of the reason for the historically poor management of private native forests in Queensland is a lack of forestry knowledge amongst landholders [26,28,29]. Landholders are often not well-informed about how to manage their forests for timber production, are not familiar with timber markets, and are unaware of the higher timber value that well-managed forests can produce as a result of faster growth rates and increased bole quality that attract higher stumpage prices. Dare et al. [29] conducted a landholder attitude survey in northern New South Wales (which is proximate to southern Queensland) where nearly 30% of respondents indicated they were not sure of the potential financial benefits of timber harvesting and 35% indicated they had no knowledge about how to manage their property for timber production. Landholders are also discouraged from investing resources in silviculture because of sovereign risk, long payback periods and other risks such as wildfire [9,26,28,29]. As predicted by economic theory, uncertainty about property rights to manage forests has been linked to increased rates of land clearing in Queensland [30].

Silvicultural treatments are known to substantially increase diameter growth, timber quality, and future harvest value in Australian native and plantation forests [31–39]. It is generally acknowledged within the Queensland hardwood timber industry that silvicultural treatments can substantially increase the commercial productivity of private native forests [40]. Lewis et al. [27] summarised data on nine silvicultural treatment tree-spacing experiments from five state forest spotted gum forests in southern Queensland with data available for between 20 and 33 years post-treatment. They found that the mean annual increment (MAI) across all nine treatment spacing trials ranged from 0.9 to 1.4 m^3/ha/year, with an average of 1.2 m^3/ha/year. In contrast, MAI in adjacent long untreated spotted gum forest was 0.35 m^3/ha/year [27]. Lewis et al. [39] used data from a total of 203 plots to assess the growth rates of treated and untreated stands, mostly dominated by spotted gum in southern Queensland. Most of these plots were located on private land (158 across 19 sites), and 45 plots were located in state forests. The average growth rates in this assessment ranged from 0.35 m^3/ha/year in unmanaged stands to 1.67 m^3/ha/year in silviculturally treated regrowth forest, with an average of 1.45 m^3/ha/year across all silviculturally treated plots. These increased growth rates could increase financial returns to landholders and increase the supply of hardwoods to industry in the medium and long-term [41].

The objective of this paper is to assess the potential financial performance of silvopastoral systems in natural forests of southern Queensland, Australia. This has been achieved by simulating the effects of silvicultural treatment and timber harvesting on pasture, cattle and wood production for five property management scenarios (including clearing for grazing) over 20 years on four case study properties in the region. The paper proceeds by outlining the methods, including details on the decision-support tool used to simulate forest growth and pasture production, as well as parameters for financial analysis. Estimates of the financial performance of alternative property management scenarios are then reported and land management and policy implications discussed.

2. Materials and Methods

Four case study properties in southern Queensland, Australia, with willing landholders, native forests dominated by spotted gum (*Corymbia citriodora* subspecies *variegata*) and forest inventory data collected by Private Forestry Service Queensland (PFSQ) and the Queensland Department of Agriculture and Fisheries, were selected for analysis. Properties dominated by spotted gum forests were selected because the decision support tool (DST) utilised to predict forest growth response to silvicultural treatments had been largely developed from spotted gum forest data [39]. The case study properties were situated near

Glenbar, Gayndah, Doughboy and Rathdowney (Figure 1). Selected characteristics of each case study property are summarised in Table 1.
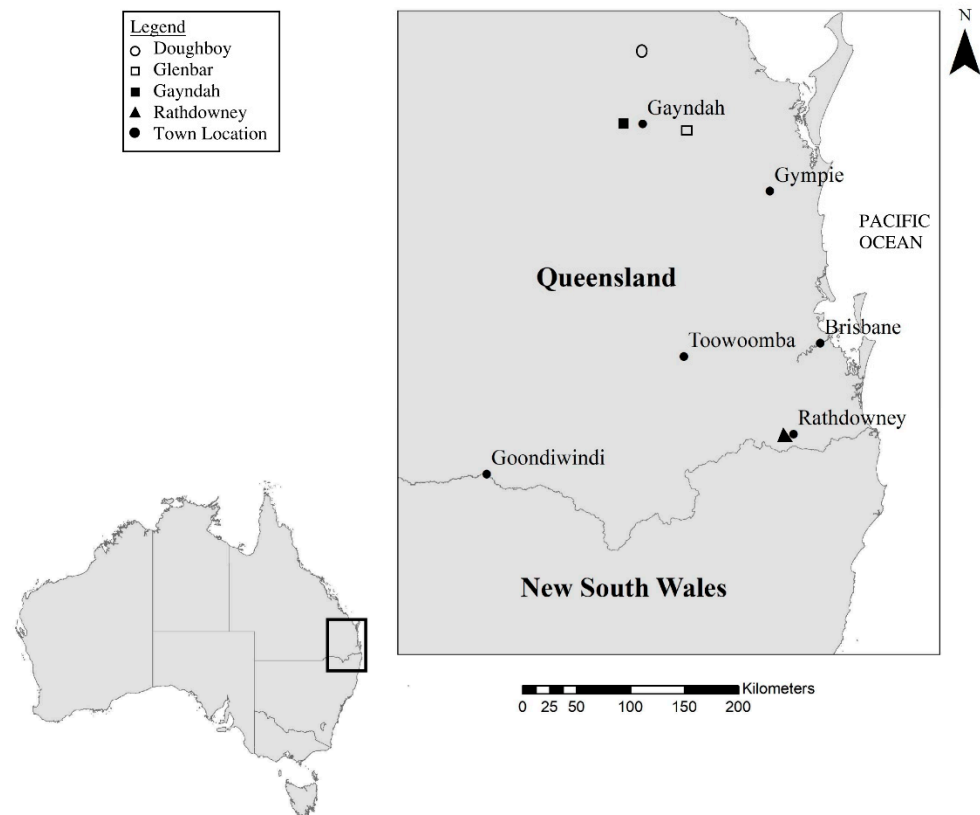

Figure 1. Case study property locations in southern Queensland, Australia. Base shape files sourced from the Australia Bureau of Statistics (https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/jul2021-jun2026/access-and-downloads/digital-boundary-files, accessed on 28 December 2021) and Queensland Spatial Catalog (https://qldspatial.information.qld.gov.au/catalogue/custom/index.page, accessed on 28 December 2021).

The DST accepts timber inventory plot data and predicts the annual growth of individual trees as a function of basal area and whether the forest is remnant or regrowth. The model, which was run in RStudio with the Shiny package, recognises individual-tree management options (e.g., silviculturally treat, harvest and retain) and product type classifications (e.g., pole, sawlog, salvage log and fencing) assigned to individual trees in the inventory data [39]. On the basis of these classifications, alternative forest management scenarios can be simulated over time and the effects on forest growth, and ultimately, wood product volumes and values, estimated per hectare.

Integrated within the DST is the Queensland Government Grass Production (GRASP) model developed by Littleboy and McKeon [42] to estimate pasture production (kg of dry matter/ha/year) as a function of tree basal area. GRASP accounts for variations in growing conditions for pasture in different parts of Queensland through the user-selection of 'land types'. Spatially explicit land types are available throughout Queensland from FORAGE Property Reports, which can be accessed via the Queensland Government website http://www.longpaddock.qld.gov.au/forage/, (accessed on 6 January 2022).

2.1. Forest Inventories on Case Study Properties

Lewis [43] detailed the inventory data collection methods. In advance of the fieldwork, desk-top evaluation of the vegetation cover on the property was completed utilising the latest available imagery, slope gradient and regional ecosystem (RE) overlays. A

combination of once-off assessments (strip-line approach) and permanent growth plots was used, depending on the property. The plots at Glenbar, Gayndah, Doughboy and Rathdowney covered 26.5, 0.99, 13.5 and 0.56 ha, respectively. Data collected for each tree within each sample area included:

- species and diameter at breast height (DBH) in cm;
- a management recommendation: whether the tree should be (a) thinned to waste (i.e., silviculturally treated), (b) harvested, (c) retained for future products, or (d) retained for environmental purposes, including as a habitat tree;
- likely product type; and
- likely product length.

Table 1. Characteristics of the four case study properties.

Property	Land Use	Dominant Timber Species	Mean Annual Rainfall [a]	Land Type
Glenbar	The property is managed for timber production only and is not generating an annual income stream from grazing.	Spotted gum (*Corymbia citriodora* subspecies *variegata)*, grey ironbark (*Eucalyptus siderophloia*), narrow-leaved red ironbark (*E. crebra*), yellow stringybark (*E. acmenoides*), and forest red gum (*E. tereticornis*)	1143 mm	Coastal Burnett ironbark and spotted gum on duplexes and loams
Gayndah	The property is primarily run as a cattle grazing enterprise, with supplementary timber production.	Spotted gum, narrow-leaved red ironbark, yellow stringybark, Gympie messmate (*Eucalyptus cloeziana*), gum-topped box (*Eucalyptus moluccana*) and forest red gum	583 mm	Gum topped box
Doughboy	The property is primarily managed for timber production with supplementary grazing.	Spotted gum, narrow-leaved red ironbark, yellow stringybark, pink bloodwood (*Corymbia intermedia*) and yellow bloodwood (*Corymbia petalophylla*), gum-topped box and forest red gum	1003 mm	Coastal Burnett ironbark and spotted gum on duplexes and loams
Rathdowney	The property is primarily run as a dairy enterprise with supplementary grazing and timber production.	Spotted gum, narrow-leaved red ironbark and gum-topped box	864 mm	Moreton ironbarks and spotted gum ridges

Notes: [a] Rainfall data sourced from the Bureau of Meteorology Australia. Glenbar (Maryborough Station, IDCJCM0027, 28 October 2021); Gayndah (Gayndah Airport Station, IDCJCM0027, 28 October 2021); Doughboy (Bundaberg Aero Station, IDCJCM0027, 28 October 2021); Rathdowney (Beaudesert Drumley Station, IDCJCM0027, 28 October 2021).

Tree management recommendations were based on improving the medium- and long-term timber value of the forest, while maintaining species diversity and forest structure (including habitat trees) in accordance with the accepted development vegetation clearing code, 'Managing a Native Forest Practice: A Self-Assessable Vegetation Clearing Guide' [44] (the Code). Trees were visually graded to industry product type standards for electricity distribution poles, sawlogs, salvage logs, and fencing materials. Trees marked for silvicultural treatment were generally in poor productive condition and not likely to be merchantable in the future (e.g., sub-dominant trees of low vigour and trees with damaged boles). Trees that could be harvested to yield a merchantable product at the time of the inventory were assigned a product type based on existing tree bole characteristics. Trees to be retained for future products were healthy, vigorous trees and were assessed according to the product type they would likely grow into.

At the time of writing, product dimensions for electricity transmission poles varied from a minimum of 9.5 m long and 225 mm diameter under bark (DUB) 2 m from butt end

(D-line), through to 30.5 m long and 565 mm DUB. Sawlogs must be at least 300 mm small end diameter under bark (SEDUB) and be a minimum of 2.4 m long, increasing in 0.3 m increments, plus 0.1 m for each crosscut. Salvage grade logs must have a minimum SEDUB of 260 mm and are usually a minimum log length of 2.4 m (occasionally, 2.1 m is accepted by sawmills). A variety of log sizes can be suitable for fencing products, and fencing is a good option for trees that are suppressed or have poor form or short bole lengths, but have wood with high durability.

2.2. Forest Management Scenarios

The Vegetation Management Act 1999 defines native forest in Queensland as being 'remnant regional ecosystems' (Category B vegetation), 'regrowth regional ecosystems' (Category C or R vegetation), or 'non-remnant' (Category X vegetation) [45]. Category X forests are not regulated by the Code; therefore, any level of forest thinning or land clearing is permitted in these forests. Simulations of native forest management scenarios were restricted to non-remnant forest (Category X) on each property because this forest category provides greater management flexibility for landholders. Additionally, at the time of publication, there was greater confidence in the non-remnant forest simulation model within the DST [39]. Five forest management scenarios were assessed with the DST for three of the case study properties over a 20-year investment period (2019 to 2038):

(1) Cleared for grazing: clear forest for grazing in 2019.
(2) Locked-up: no silvicultural treatment or harvesting in 2019, to be followed by a harvest in 2038, which was designed to represent a forest in poor productive condition.
(3) Silviculturally treated: silvicultural treatment in 2019 and harvest in 2038.
(4) High-graded: harvest in 2019 and harvest in 2038, which was designed to represent a high-graded forest.
(5) Silviculturally treated and harvested: silvicultural treatment and harvest in 2019, to be followed by a harvest in 2038.

Insufficient standing volumes of merchantable timber were identified during the inventory assessment at the Rathdowney property to support a harvest in 2019. Consequently, only the first three forest management scenarios were assessed for that site. Cattle grazing was assumed in all scenarios, and grazing was concurrent with timber production in scenarios 2 to 5. Examples of properties that are cleared for grazing, locked-up, silviculturally treated and high-graded are presented in Figure 2.

2.3. Simulation of Forest Management Scenarios with the Decision Support Tool

A discounted cash flow analysis was conducted to assess the NPV of each management scenario in 2019 dollars using a real (net of inflation) discount rate of 5%. The analysis did not accommodate income tax and tax deductions. Parameter levels adopted for the financial analysis are reported in Table 2. Up-front investments were designated as occurring at the beginning of 2019 (i.e., year zero) and were not discounted. All other costs and revenues from 2019 to 2038 (also referred to as years 1 to 20) were assumed to be paid or received at the end of the year and have been discounted as appropriate. The tordon treatment costs proposed in Table 2 compare favourably with Francis et al. [40], who determined tordon treatment costs to be AUD 349/ha when tordoning a stand with an initial stocking of 1000 stems per hectare (SPH) down to 250 SPH. Two sawlog price levels are listed for year 20 because silviculturally treated forests were assumed to have a higher average level of sawlog quality, attracting a higher mean sawlog stumpage price. Timber revenues generated by each forest management scenario on each property were estimated as the DST-simulated harvest volume multiplied by the stumpage price.
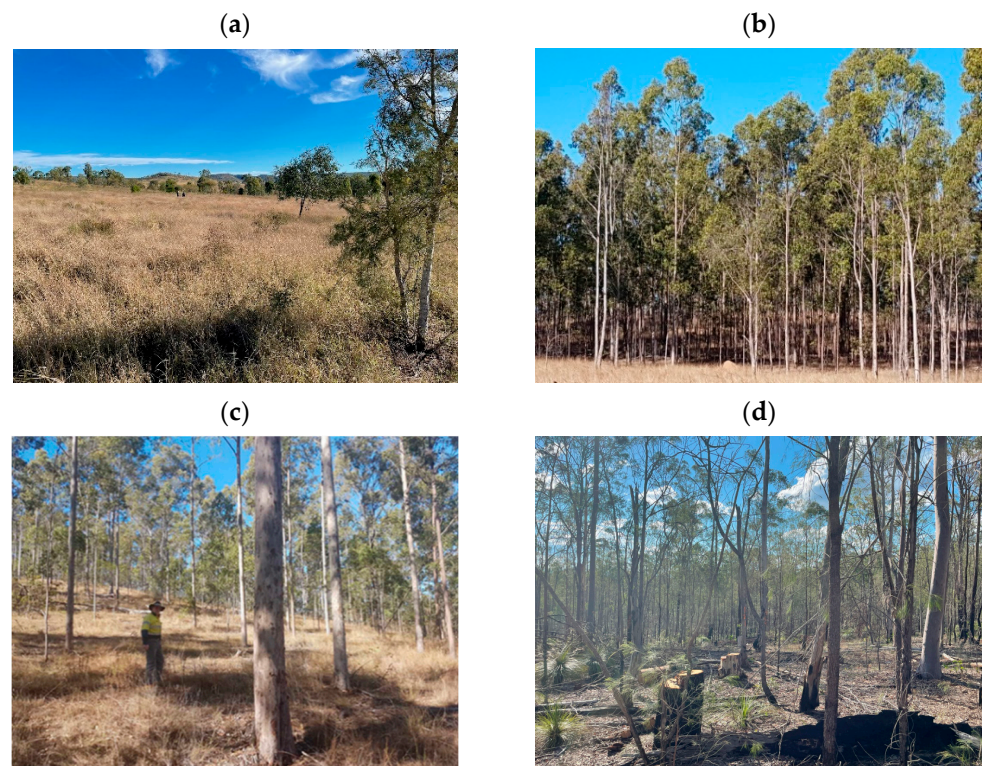
Figure 2. (**a**) Cleared land for grazing; (**b**) locked-up forest; (**c**) silviculturally treated forest; (**d**) high-graded forest. Note: Silviculturally treated and harvested forests look similar to silviculturally treated forests, with the difference being that commercial products are harvested during treatment.

Table 2. Parameter levels adopted for the financial analysis of forest management scenarios.

Parameter	Year	Level
Discount rate (%)		5
Forestry		
Paint marking of retained trees (not harvested or silviculturally treated) (AUD/ha) [a]	0	100
Contract tordoning silvicultural treatment cost in 2019 (AUD/ha) [a]	0	350
Stumpage prices (AUD/m^3) [a]		
Sawlog (no silvicultural treatment)	0 and 20	80
Sawlog (following silvicultural treatment in year 0)	20	100
Pole	0 and 20	150
Salvage class logs	0 and 20	20
Pile	0 and 20	30
Fencing	0 and 20	35
Grazing		
Land clearing and pasture establishment costs (AUD/ha) [a]	0	500
Cattle annual feed requirement (kg/adult equivalent/year) [a]	annual	3650
Liveweight gain per adult equivalent (kg/year) [a,b]	annual	100–150
Liveweight farmgate price (AUD/kg) [c]	annual	2.54

Notes: [a] Expert opinion from Private Forestry Service Queensland (PFSQ). [b] Varies for each site based on pasture quality. Glenbar 130 kg/year, Gayndah 150 kg/year, Doughboy 150 kg/year and Rathdowney 100 kg/year. [c] Weighted average price derived from meat and livestock saleyard reports for manufacturing steers, grown heifers, vealer heifers, vealer steers, yearling steers, yearling heifers, bulls and cows between 2015 and 2018 for Rockhampton and Toowoomba markets (https://www.mla.com.au/prices-markets/market-reports-prices/, last accessed on 16 September 2021).

It was assumed there would be no timber volume or income generated from clearing for grazing. Forest management scenarios 2 to 5 differ in terms of management activity and timber income in year zero, although all four scenarios have a timber harvest generating

income in year 20. In the locked-up scenario, there is no management activity in year zero, and the DST simulated the growth of all inventoried trees over the next 20 years. In the silviculturally treated scenario, all trees classified in the inventory as 'thinned to waste' were simulated as culled in a silvicultural treatment, and the growth of the remaining stems was projected over 20 years. In the high-graded scenario, trees identified as merchantable at the time of the inventory were simulated to be harvested for income in year zero, and the growth of all remaining stems was projected over 20 years. In the silviculturally treated and harvested scenario, the simulation culled all stems marked for silvicultural treatment and harvested all stems classified as merchantable at the time of the inventory. The growth of all remaining stems was projected over 20 years.

In estimating harvest volume and value in year 20 (2038), it was assumed that up to 80% of the standing merchantable volume of stems at least 30 cm DBH could be harvested. Depending on the stocking at the time of harvest, this may result in the non-achievement of requirements to retain particular numbers of stems by diameter class under the Code. This was permitted in the analysis because harvesting in Category X land, as considered in this analysis, is not regulated by the Code. Nevertheless, simulated harvesting was forced to adhere to the habitat tree and recruitment habitat tree retention requirements of the Code.

In evaluating grazing costs and revenues, land clearing and pasture establishment costs were treated as an up-front investment in year 0 for the clear for grazing scenario. The effect of each forest management scenario on cattle carrying capacity was assessed over a 20-year period with GRASP. The land types adopted for analysis of pasture production are presented in Table 1.

The projected basal area of trees from the DST in each year of the simulation was used in GRASP to estimate pasture production in each simulated year. Cash flows over the 20-year investment period were then estimated as follows. Pasture production was divided by annual feed requirement (Table 2) to estimate annual cattle carrying capacity (*CC*) or stocking rate in adult equivalents (AE) per hectare. The AE standard unit is a 450 kg *Bos taurus* steer at 2.25 years of age [46]. Grazing revenue (*GR*) in dollars per hectare was then estimated with Equation (1) for each year. *Live weight gain* and *live weight farm gate price* are reported in Table 2.

$$GR = CC \times \textit{live weight gain} \left(\frac{\text{kg}}{\text{yr}} \right) \times \textit{live weight farm gate price} \left(\frac{\text{AUD}}{\text{kg}} \right) \quad (1)$$

where *GR* is grazing revenue and *CC* is the annual cattle carrying capacity.

3. Results

Table 3 reports standing volumes from the forest inventory, indicating retained and harvested volumes in 2019 for all management scenarios except clear for grazing. Clear for grazing is not included, as no trees are retained. Product volumes and total standing volumes presented in the locked-up scenario represent the stand characteristics prior to treatment. The difference in total retained volumes between the locked-up and silviculturally treated scenarios is the thinned-to-waste volume. The difference in total retained volumes between the locked-up scenario and the high-graded scenario is the volume of harvested stems. The difference in total retained volumes between the locked-up and the silviculturally treated and harvested scenario is the volume of harvested and thinned stems. No values are presented for the high-graded or silviculturally treated and harvested scenarios at Rathdowney because insufficient standing volumes of merchantable timber were identified during the inventory.

The DST-simulated growth of the stands is summarised in Table 3 over 20 years to generate the projected stand structures and harvest volumes reported in Table 4 in 2038. The simulated MAI (m^3/ha/year) of merchantable timber volume over the 20-year period is also presented. Silvicultural treatments maximised growth response, with MAIs ranging from 0.5 m^3/ha/year in the high-graded scenario to 3.1 m^3/ha/year in the silviculturally treated scenario.

Table 3. Stems per hectare and product volumes in 2019 for each property and scenario.

Stand Characteristic by Scenario in 2019	Case Study Property			
	Glenbar	**Gayndah**	**Doughboy**	**Rathdowney**
Locked-up				
Stand density (sph)	540	285	168	284
Retained volume (m³/ha)				
Sawlog	8.2 (46%)	5.6 (49%)	15.9 (71%)	10.3 (38%)
Pole	1.8 (10%)	2.1 (18%)	0.0 (0%)	1.1 (4%)
Other	2.1 (12%)		2.7 (12%)	
Non-merchantable	5.6 (31%)	3.7 (33%)	3.7 (17%)	15.7 (58%)
Total retained volume (m³/ha)	17.7	11.36	22.38	27.01
Silviculturally treated				
Stand density (sph)	111	60	47	137
Retained volume (m³/ha)				
Sawlog	8.2 (61%)	5.6 (73%)	15.9 (82%)	10.3 (71%)
Pole	1.8 (14%)	2.1 (27%)	0.0 (0%)	1.1 (7%)
Other	2.1 (16%)		2.7 (14%)	
Non-merchantable	1.2 (9%)		0.7 (4%)	3.1 (22%)
Total retained volume (m³/ha)	13.4	7.7	19.4	14.4
High-graded				
Stand density (sph)	534	281	149	
Harvested volume (m³/ha)				
Sawlog	1.4 (40%)	2.8 (73%)	12.7 (83%)	
Pole		1.1 (27%)		
Other	2.1 (60%)		2.7 (17%)	
Total harvested volume	3.5	3.9	15.4	
Retained volume (m³/ha)				
Sawlog	6.8 (48%)	2.8 (37%)	3.2 (46%)	
Pole	1.8 (13%)	1.0 (14%)	0.0 (1%)	
Other				
Non-merchantable	5.6 (39%)	3.7 (49)	3.7 (53%)	
Total retained volume (m³/ha)	14.2	7.5	7.0	
Silviculturally treated and harvested				
Stand density (sph)	104	56	29	
Harvested volume (m³/ha)				
Sawlog	1.4 (39%)	2.8 (72%)	12.7 (82%)	
Pole		1.1 (28%)		
Other	2.1 (58%)		2.7 (18%)	
Total harvested volume	3.6	3.9	15.4	
Retained volume (m³/ha)				
Sawlog	6.8 (69%)	2.8 (73%)	3.2 (81%)	
Pole	1.8 (18%)	1.0 (27%)	0.0 (1%)	
Other				
Non-merchantable	1.2 (13%)		0.7 (18%)	
Total retained volume (m³/ha)	9.9	3.8	4.0	

The silviculturally treated scenario maximised product volumes at the final harvest for all sites (Table 4). The silviculturally treated and harvested scenario provided the second-highest harvest volume in year 20 at all sites except Doughboy. This is because Doughboy had a high proportion of harvestable stems in year zero, which resulted in a large proportion of stems being removed in the silviculturally treated and harvested scenario in the initial treatment. The locked-up scenario resulted in the second-highest harvest volumes at Doughboy.

Table 4. Mean annual increment and product volumes in 2038.

Stand Characteristic by Scenario in 2038	Case Study Property			
	Glenbar	Gayndah	Doughboy	Rathdowney
Locked-up				
MAI (m^3/ha/year)	1.1	0.8	2.1	0.8
Harvested volume (m^3/ha)				
Sawlog	16.7 (69%)	6.8 (47%)	32.6 (80%)	17.2 (100%)
Pole	2.5 (10%)	2.4 (26%)		
Other	5.1 (21%)		8.2 (20%)	
Total harvested volume	24.3	9.2	40.8	17.2
Retained volume (m^3/ha)				
Sawlog	2.7 (12%)	7.9 (23%)	2.3 (16%)	6.3 (16%)
Pole	4.5 (20%)	1.7 (5%)	0.1 (1%)	2.0 (5%)
Other			0.1 (1%)	
Un-merchantable	15.1 (68%)	25.3 (72%)	11.3 (82%)	30.9 (79%)
Total retained volume	22.3	34.9	13.8	39.2
Silviculturally treated				
MAI (m^3/ha/year)	2.4	2.0	3.1	2.1
Harvested volume (m^3/ha)				
Sawlog	28.6 (64%)	15.2 (65%)	44.1 (79%)	27.5 (80%)
Pole	9.9 (22%)	8.1 (35%)		6.9 (20%)
Other	6.2 (14%)		11.9 (21%)	
Total harvested volume	44.7	23.3	56.0	34.4
Retained volume (m^3/ha)				
Sawlog	5.8 (43%)	20.3 (96%)	4.7 (68%)	16.8 (70%)
Pole	4.7 (35%)	0.8 (4%)	0.1 (1%)	1.7 (7%)
Other	0.3 (2%)		0.1 (1%)	
Non-merchantable	2.8 (20%)		2.0 (29%)	5.5 (23%)
Total retained volume	13.6	21.1	6.9	24
High-graded				
MAI (m^3/ha/year)	0.8	0.5	0.5	
Harvested volume (m^3/ha)				
Sawlog	14.8 (85%)	2.0 (59%)	7.6 (96%)	
Pole	2.7 (15%)	1.4 (21%)	0.1 (1%)	
Other			0.2 (3%)	
Total harvested volume	17.5	3.4	7.9	
Retained volume (m^3/ha)				
Sawlog	2.5 (11%)	8.4 (22%)	3.2 (14%)	
Pole	4.8 (20%)	1.4 (4%)	0.1 (0.5%	
Other			0.1 (0.5%	
Un-merchantable	16.3 (69%)	27.6 (24%)	19.2 (85%)	
Total retained volume	23.6	37.4	22.6	
Silviculturally treated and harvested				
MAI (m^3/ha/year)	2.0	1.7	1.0	
Harvested volume (m^3/ha)				
Sawlog	27.5 (68%)	8.7 (55%)	13.4 (94%)	
Pole	12.8 (32%)	7.0 (45%)	0.4 (3%)	
Other			0.5 (3%)	
Total harvested volume	40.3	15.7	14.3	
Retained volume (m^3/ha)				
Sawlog	4.7 (41%)	21.2 (100%)	7.3 (74%)	
Pole	4.0 (34%)			
Other				
Non-merchantable	2.9 (26%)		2.5 (26%)	
Total retained volume	11.6	21.2	9.8	

Figure 3 presents the distribution of stems within diameter size classes for each scenario in 2019 (left) and 2038 (right). Scenarios that involved a thinning treatment

resulted in a higher proportion of larger stems in 2038. This was evident at all sites where there were more stems >30 cm DBH in 2038 for the silviculturally treated and silviculturally treated and harvested scenarios than the scenarios with no silvicultural treatment. This resulted in a greater number of retained stems in the higher size classes (>40 cm) for the silviculturally treated scenario. The high-graded and locked-up scenarios resulted in the highest proportions of stems in the 20–30 cm size class in 2038 across all case study properties. This reflects the fact that these management scenarios produce low-productivity stands dominated by small, non-commercial stems.
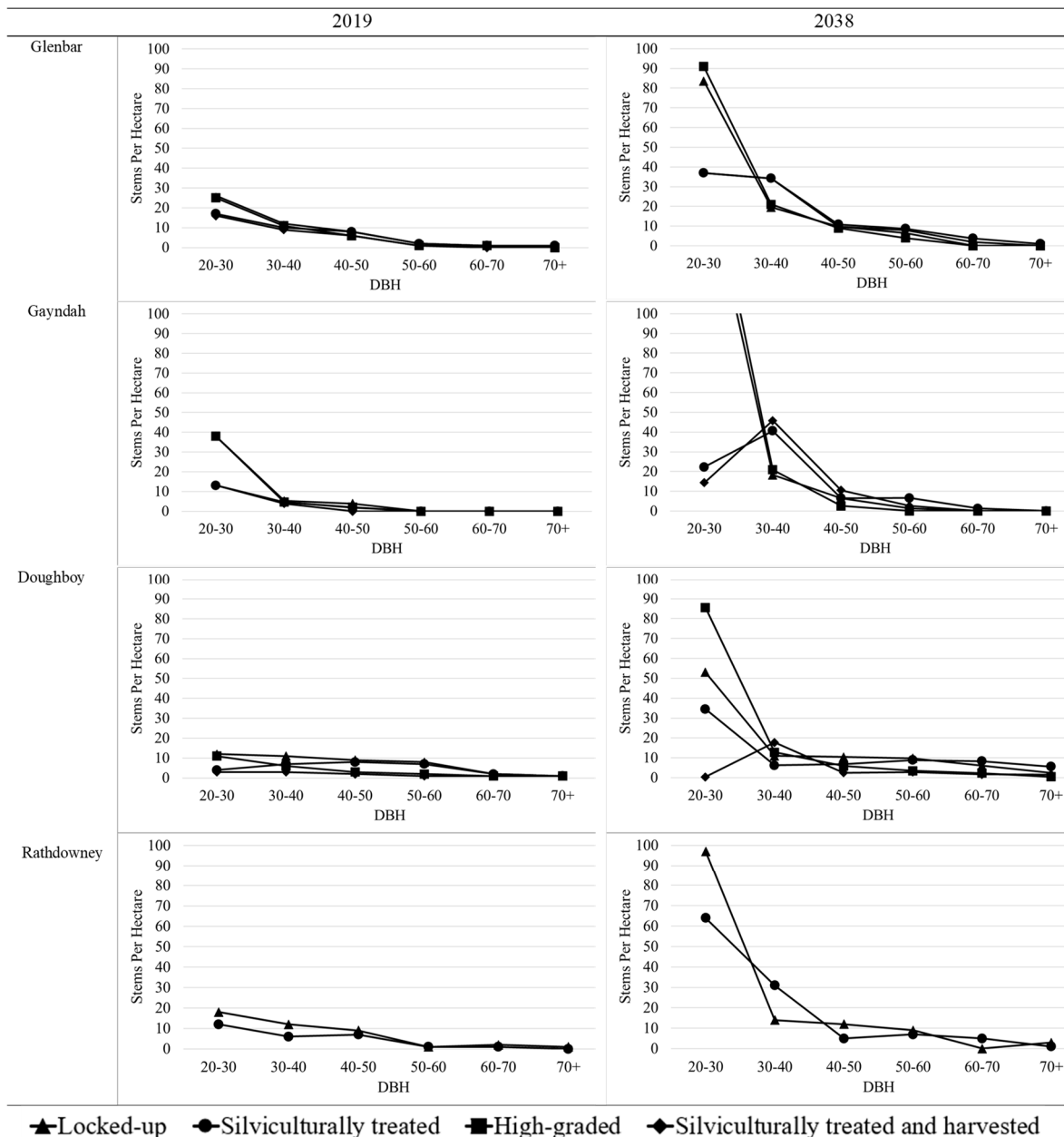
Figure 3. Stocking following treatment in year zero (**left**) and before harvest in year 20 (**right**). DBH (cm) is presented in a range of categories. Note: Where lines are not visible for all four scenarios, the scenarios overlap each other and follow a similar diameter distribution in SPH. In 2038, the silvicultural treatment (only), and harvest and silvicultural treatment scenarios follow a similar diameter distribution and the locked-up and high-graded scenarios follow a similar diameter distribution at both Glenbar and Gayndah. For the Rathdowney site, only the locked-up, silviculturally treated and clear for grazing scenarios were assessed as no stems were available for harvest in the inventory.

There were substantial differences in CC between properties, and, as expected, CC was always highest where forest clearing took place (Figure 4). In all scenarios where trees were retained, CC declined over time as the retained trees grew. The locked-up forest produced the lowest CC at all properties. The silviculturally treated and harvested scenario had the highest CC, producing approximately double the CC of the locked-up forest for the three case study properties where this scenario was applicable. At Glenbar and Gayndah, the silviculturally treated forest generated a higher CC than the high-graded scenario, as would be expected.
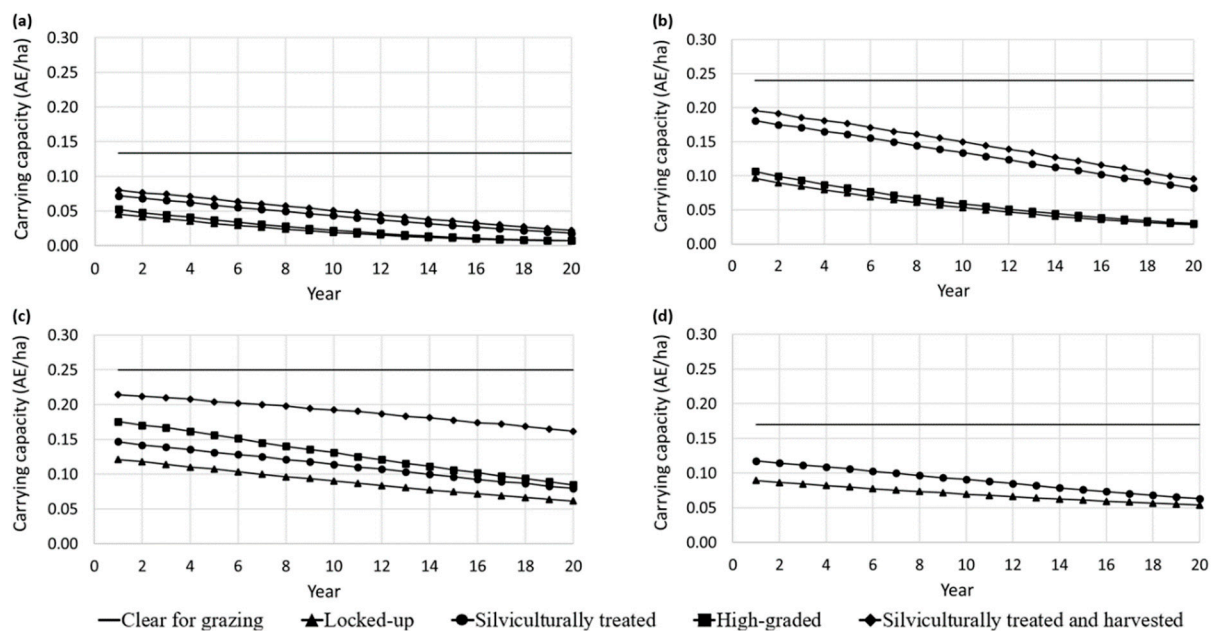
Figure 4. Projected cattle carrying capacity in regrowth forest between 2019 (year 1) and 2038 (year 20). (**a**) Glenbar, (**b**) Gayndah, (**c**) Doughboy, and (**d**) Rathdowney.

Figure 5 indicates the present values of costs and revenues as well as NPVs per hectare for each case study property by management scenario. There were substantial differences in grazing and timber revenues observed between case study sites, although scenarios that incorporated a silvicultural treatment consistently maximised their NPV. For the three case study properties where the silviculturally treated and harvested scenario was possible, this scenario returned the highest NPV: AUD 1532/ha for Glenbar, AUD 1406/ha for Gayndah and AUD 2396/ha for Doughboy. With no harvest available in 2019 for Rathdowney, the silvicultural treatment scenario returned the highest NPV of AUD 1405/ha. Timber production alone in the silviculturally treated and harvested scenario (NPV minus grazing revenues) produced higher NPVs than the cleared for grazing scenario at Glenbar and Doughboy. However, the financial performance of managing the forest under a silvopastoral system with joint cattle and timber production provided the highest NPV for all case study properties.

The clear for grazing scenario generated the lowest NPV in all four case studies despite this scenario maximising CC, which provided the highest annual farm income. The locked-up scenario returned the lowest grazing revenues because there was no opening up of the forest with a silvicultural treatment or harvest in year zero. Nevertheless, the locked-up scenario returned a higher NPV than clearing for grazing for all properties as a result of the harvested timber value in 2038. Table 4 highlights that the locked-up forest was in a low productive state by 2038, with low MAI and high retained non-merchantable volume. The two scenarios with silvicultural treatment almost always outperformed the remaining scenarios because the treatments improved timber and cattle production.
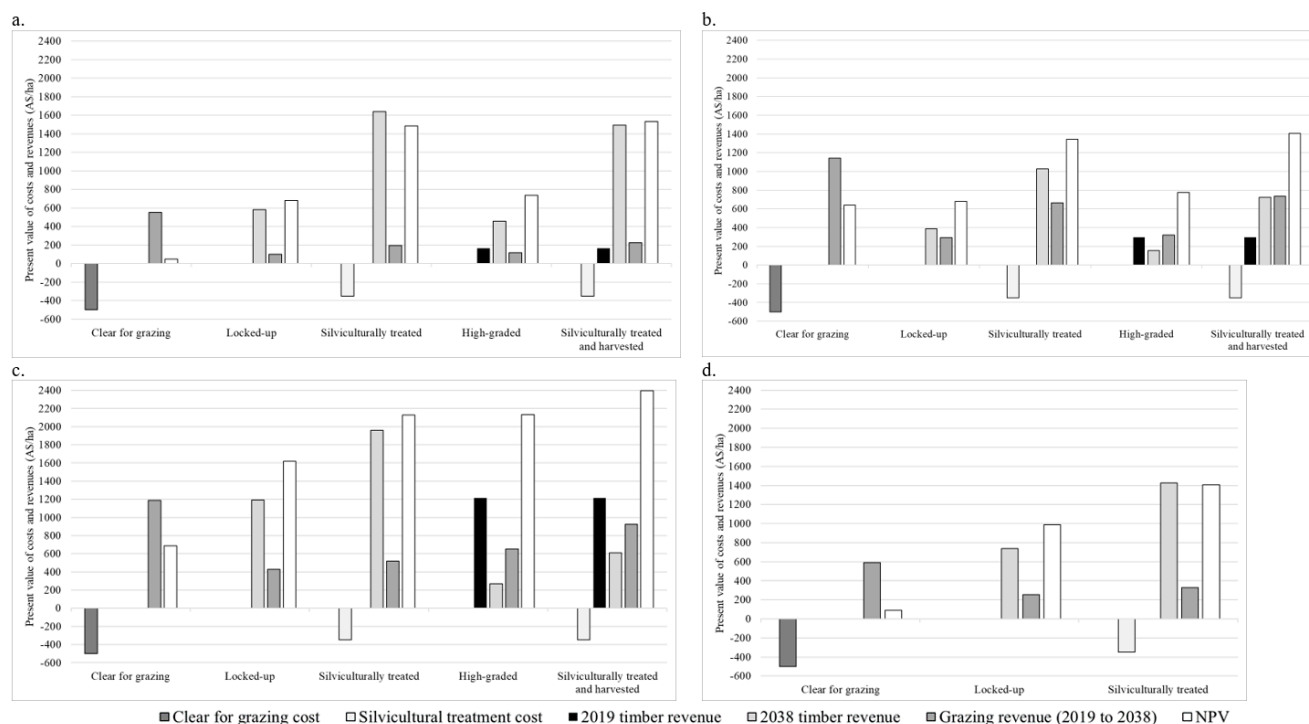
Figure 5. Present value of costs and revenues, and NPVs per hectare by management scenario. (**a**) Glenbar, (**b**) Gayndah, (**c**) Doughboy, and (**d**) Rathdowney.

4. Discussion

This study assessed five silvopastoral system management scenarios (including clearing forest for grazing) for four case study properties. By evaluating various properties, we were able to assess the financial performance of silvopastoral systems across a range of forest and pasture growing conditions. With one exception discussed below, the silvicultural treatment (only), and silvicultural treatment and harvest scenarios, which both included thinning treatments to maximise the growth of merchantable wood, generated higher NPVs than all other scenarios. The combination of high timber values and relatively high grazing values makes silviculturally treated forests managed for timber and livestock the long-term wealth-maximising choice for landholders. This finding is consistent with the financial analyses of silvopastoral systems internationally [11,16] and in Queensland [18,47].

The silvicultural treatment scenario substantially increased projected timber growth rates, resulting in higher timber revenues in 2038 than all other scenarios for all case study properties. These findings are consistent with silvicultural treatment studies conducted both in Australia and internationally [35,36,38,48,49]. The silviculturally treated scenario had the highest projected MAIs for all properties, averaging 2.4 m^3/ha/year over 20 years across the four properties. This is 1.3 m^3/ha/year greater than the average of the MAIs for the locked-up forest scenario across all properties. This growth response simulated by the DST for the silviculturally treated scenario is comparable with the scarce literature that has assessed the growth potential of native forests in southern Queensland [27,28,39].

The high-graded scenario, where there was no regard for the forest's future productivity, resulted in the lowest MAI of merchantable timber for all case study properties because the productive condition of the forest was negatively impacted by selection harvesting of the higher quality trees in 2019 without follow-up silvicultural treatment. The resulting stand had a high proportion of unmerchantable trees, often including a high density of small, competing stems. This can be observed in Figure 3, where the high-graded scenario shows a high proportion of stems in the lower DBH classes and a lower proportion of stems in the higher DBH classes in 2038 when compared with scenarios that include a

silvicultural treatment. This is consistent with reported effects of high-grading in Australian and international literature [25,27,28,50–52].

The high-graded scenario always generated the highest net cash flow in 2019 but generally lower returns over 20 years than the two scenarios with silvicultural treatment. Doughboy was the only property where the high-graded scenario outperformed a silvicultural treatment scenario. This was because of the relatively large harvestable volumes in 2019 (Table 3), coupled with the absence of silvicultural treatment cost. These findings are consistent with Jay and Dillon [21], who found that high-grading is a rational choice for landholders in the short term. That study also suggested that silviculture produces better outcomes for landholders in the long term (after 15 years); however, the up-front costs and long payback period was likely to be a deterrent.

Locked-up stands result in intense competition between merchantable and non-merchantable trees, as well as suppression of regeneration [26]. This was observed in our results, with the locked-up scenario always returning the lowest timber values out of the four scenarios where trees were retained. The locked-up scenario also returned the lowest grazing revenues because there was no opening up of the forest with a silvicultural treatment or harvest in year zero. Cattle carrying capacity in the locked-up scenario averaged about 25% of the level achievable if the land had been cleared for grazing.

By producing a forest with more widely spaced trees, silvicultural treatments increase grass production, cattle CC and, consequently, grazing revenues relative to the locked-up and high-graded scenarios. The predicted grazing revenues in the silviculturally treated scenarios averaged at least 50% of the grazing revenues of the clear for grazing scenario in three of the four case studies. This implies that at least about 50% of potential grazing revenues can be gained from a fraction of the investment necessary to clear regrowth forest for grazing. For business accounting purposes, the up-front investment in silvicultural treatment necessary to achieve this grazing outcome should be shared between the timber and cattle production elements of the business. By incorporating grazing into thinned forests, annual cash flow limitations associated with tree production can be mitigated [7]. For all scenarios except clear for grazing, the DST projected that cattle CC decreased over time (Figure 4). This is because as trees grow and basal area increases, pasture production is reduced as shade increases from canopy closure [53,54]. Although cattle CC decreases over time, scenarios with silvicultural treatment remain financially optimal because the decline in pasture production is offset by periodic financial returns from timber. There are also less tangible benefits of trees for livestock wellbeing and pasture quality that have not been accommodated in the analysis [18,55].

Clearing forest for grazing was shown to generate the highest annual income stream for landholders (highest PV of grazing revenues); however, this scenario generated the lowest NPV for all case study properties. The calculated NPVs of clearing for grazing in this study compare favourably with Schulke [17]. Estimates of the NPV of gross margins for cleared brigalow country, which is west of our Queensland study area, are lower than we have estimated, with values ranging from AUD 320/ha to AUD 550/ha [18,56,57]. Maraseni and Cockfield [47] reported the NPV of gross margins from grazing on cleared land around Kingaroy at AUD 3079/ha over 34 years of operation at a discount rate of 6%. This is higher than our estimates; however, that site appears to be highly productive, with an annual rainfall of 781 mm, red ferrosol soils and an average cattle-carrying capacity of 0.56 head per hectare.

Although the research revealed silvopastoral systems generate higher returns than clearing for grazing, it is rational that landholders who are dependent on their property to generate an annual income would seek to clear their Category X forests to maximise annual income. However, if landholders could accept a lower annual income stream while waiting for their native forest timber crop to mature, the financial performance of their enterprise would be substantially increased in the long term. Additionally, by integrating grazing with timber production, landholders have the added benefit of income diversification [8,58].

This research and other studies relevant to Queensland have found that silvopastoral systems are financially superior to grazing or timber production alone in southern Queensland; however, there is a lack of knowledge amongst landholders about this potential. Funding for extension services to inform landholders and increase their capacity to manage forests could facilitate increased cattle and timber production across a large proportion of the 2.1 million hectares of harvestable private native forest in southern Queensland. This would diversify and increase farm incomes, as well as have broader employment and income benefits for the beef and timber industries in rural southern Queensland. Although landholders are not homogeneous and not all landholders are interested in managing their forests for timber production [59], there is strong landholder interest in forest management extension services in southern Queensland [60].

Widespread adoption of silvopastoral systems is constrained by the need of landholders to make an annual income from their properties. At least in the short- and medium-term, cleared paddocks will produce higher annual income streams than paddocks managed as silvopastoral systems. The approximately 20-year payback period for investment in native forest silviculture may be beyond the planning horizon of many landholders. Venn [9] described an annuity payment scheme costing AUD 4.2 million per year that could be funded by the private or public sector to encourage landholders to manage the 100,000 ha of native forest for timber. The scheme could generate a 5% real rate of return on investment from timber values and be self-sustaining when timber harvests commence in year 20. Government funding of such a scheme could be justified on the basis of supporting the hardwood timber industry to adjust to the 2024 withdrawal from production of state forests in the SEQ regional plan area, as well as supporting farmers to diversify their businesses, improve management of their forests and increase the provision of public goods (e.g., carbon sequestration and biodiversity conservation).

Several studies have shown that landholders are also discouraged from investing in silviculture because of sovereign risk [26,29,61]. Landholders require certainty that if they invest money in forest management, they will be permitted to harvest their crop in 20 to 30 years. Therefore, reducing sovereign risk with accommodating government policy is required to encourage the widespread adoption of silvopastoral systems.

There are several limitations with the case study analysis reported here, which should be considered when interpreting the findings. First, a typical silvicultural treatment schedule would include a follow-up treatment about 10 years after the initial treatment, which the DST used to simulate forest growth does not presently accommodate. The follow-up treatment would result in higher costs but also faster tree growth and increased future timber revenues relative to the case study analyses presented. Francis et al. [40] indicated that the financial viability of silvicultural treatments in southern Queensland is not negatively affected by the need to re-treat the forest. Second, in the cleared for grazing scenario, it was assumed that landholders are not interested in timber, having no regard for the log value. While this is relatively common, it is possible that a timber harvest could be performed prior to clearing for grazing, which could increase revenues to the landholder. Third, this case study analysis considered only regrowth (Category X) forests dominated by spotted gum because the DST has been parameterised with data for this forest type. Research into the financial performance of silvicultural treatments in other forest types and remnant forests (Category B, as opposed to regrowth forests on Category X) is needed. Further limitations associated with the use of the DST are presented by Lewis et al. [39]. Fourth, ongoing costs of cattle management (e.g., feed and pasture improvement) were not included, which may have led to an overestimate of the returns to cattle in each forest management scenario. Future research should aim to accommodate cattle management costs in the analysis.

5. Conclusions

With uncertainty surrounding the future of timber harvesting in state-owned forests in southern Queensland, it is likely that the hardwood timber industry will be increasingly

reliant on privately owned forests to meet future timber demands. This is a concern because, after decades of poor management, including high-grading, much of the privately-owned native forest area is in low productive conditions. The majority of these forests are on properties managed for cattle production. This case study analysis has revealed that investment in private native forest management in southern Queensland is financially attractive, particularly under silvopastoral systems. However, long payback periods and sovereign risk are serious impediments to silvopastoral system adoption. If these concerns can be mitigated in southern Queensland, private native forests have the potential to be sustainably managed to improve the financial performance of farms, improve regional employment and income generation, supply Queensland's future hardwood timber needs, and increase carbon sequestration and biodiversity conservation on private land.

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