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Bioeconomic modelling of woody regrowth carbon offset options in productive grazing systems

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Abstract. Agricultural land has been identified as a potential source of greenhouse gas emissions offsets through biosequestration in vegetation and soil. In the extensive grazing land of Australia, landholders may participate in the Australian Government's Emissions Reduction Fund and create offsets by reducing woody vegetation clearing and allowing native woody plant regrowth to grow. This study used bioeconomic modelling to evaluate the trade-offs between an existing central Queensland grazing operation, which has been using repeated tree clearing to maintain pasture growth, and an alternative carbon and grazing enterprise in which tree clearing is reduced and the additional carbon sequestered in trees is sold. The results showed that ceasing clearing in favour of producing offsets produces a higher net present value over 20 years than the existing cattle enterprise at carbon prices, which are close to current (2015) market levels (~\$13 t^{-1} CO_2-e). However, by modifying key variables, relative profitability did change. Sensitivity analysis evaluated key variables, which determine the relative profitability of carbon and cattle. In order of importance these were: the carbon price, the gross margin of cattle production, the severity of the tree–grass relationship, the area of regrowth retained, the age of regrowth at the start of the project, and to a lesser extent the cost of carbon project administration, compliance and monitoring.

Based on the analysis, retaining regrowth to generate carbon income may be worthwhile for cattle producers in Australia, but careful consideration needs to be given to the opportunity cost of reduced cattle income.

Additional keywords: brigalow, beef production, climate change mitigation, greenhouse gas emissions, options modelling, sequestration.

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Introduction

The Queensland agricultural industry is responsible for between 4% and 6% of Australia's total greenhouse gas emissions (DoE 2015*a*) but also generates over \$9.5 billion per annum in gross value of production (ABS 2015). The primary sources of agricultural emissions in this sector are enteric methane emissions from beef cattle (Charmley *et al*. 2008; Bray and Willcocks 2009; Rolfe 2010). Although the industry is a significant contributor to emissions, potential opportunities exist to develop carbon offsets from sequestration in vegetation and soil and from improvements in herd emission intensity. A carbon offset is defined as one tonne of carbon dioxide equivalent (CO_2-e), which is a reduction in emissions or sequestration of carbon in soil or vegetation to balance a tonne of emissions elsewhere. The International Panel on Climate Change (IPCC) has estimated that the global technical potential of agriculture to contribute to emissions offsets is in the range of 5500–6000 million tonnes of carbon dioxide equivalent (Mt CO_2-e) per year (Smith *et al*. 2007). It has been estimated that there is biophysical potential for up to 623 Mt CO_2-e to be sequestered through afforestation alone in Australia over the period 2007–2050 (Lawson *et al*. 2008). However, a review of options for biosequestration in Queensland identified that only 10–15% of the biophysical potential was likely to be realised due to economic, social, technical and policy constraints (Eady *et al*. 2009).

This paper presents the results of a case study designed to test the impact of a range of economic, technical and policy variables on the viability of a regrowth retention carbon offsets enterprise for a grazing operation in central Queensland, Australia. The potential ability for landholders to participate in a carbon trading scheme exists due to the Australian Government's Emissions Reduction Fund (ERF). The ERF is a government-funded program designed to purchase the most cost-effective emissions reductions across economic sectors. Approved ERF methodologies with potential application in grazing land include:

– Avoided clearing of native regrowth,
– Native forest from managed regrowth,
– Savanna fire management,

– Designated verified carbon standard projects (forestry),
– Reducing greenhouse gas emissions in beef cattle through feeding nitrate containing supplements,
– Sequestering carbon in soils in grazing systems, and
– Beef cattle herd management.

The ERF replaced the earlier Carbon Farming Initiative. The first two ERF auctions were held in 2015 and resulted in 275 contracts being awarded for over 92.8 Mt CO_2-e of abatement (Clean Energy Regulator 2015). The majority of contracted projects were based on sequestration and landfill and waste management, and were traded for an average \$13.12 t^{-1} CO_2-e abated (Clean Energy Regulator 2015).

For landholders considering whether to participate in the ERF, the comparative profitability of a carbon enterprise over their existing enterprise is crucial. Estimates for carbon sequestration within a pasture-cropping system suggest that the breakeven price could be over \$60 t^{-1} CO_2-e (Kragt *et al*. 2012), whereas estimates for changing sheep production practices to reduce methane emissions could require carbon prices of over \$150 t^{-1} CO_2-e (Alcock *et al*. 2015). Establishing a farm forestry or environmental plantings sequestration project on marginal agricultural land may be economically viable with a carbon price <\$18 t^{-1} CO_2-e (Paul *et al*. 2013).

To analyse the relative returns of cattle and carbon in the absence of substantial market data, a bioeconomic model was developed specifically designed to allow the relevant biophysical and economic variables to be integrated and a range of scenarios to be tested.

Bioeconomic modelling

Bioeconomic modelling combines ecological, environmental and economic variables to determine the efficient allocation of resources or evaluate the impact of resource allocation decisions. The bioeconomic modelling field developed out of the need to model complex relationships in dynamic settings, and thus provide information, which could be used to design more effective policies and more efficient targeting of investment. Agro-ecological models can predict yields and ecological impacts under various environmental conditions but not the economic outcome (Ruben *et al*. 1998). The first examples of the integration of biophysical, harvesting and economic factors were in the fishing and forestry sectors, where models were used to calculate optimal extraction rates (Clark 1990). Bioeconomic models are now a common tool used to assist farmers in decision making and to evaluate policy implications.

Examples of bioeconomic models used in Australia include the Agricultural Production Systems Simulator (APSIM), which models the biophysical, economic and ecological elements of cropping systems, and is used to assess climate risk and soil carbon sequestration (Keating *et al*. 2003; Luo *et al*. 2011). The Model of an Integrated Dryland Agricultural System (MIDAS) dry-land cropping system model has been in use for over 25 years (Pannell 2007) and has recently been applied to estimate the trade-offs between profit and soil carbon sequestration in a crop–pasture rotation (Kragt *et al*. 2012). Recently, the livestock economics model ENTERPRISE has been coupled to output from the grass production (GRASP) model to evaluate the biophysical and economic impact of grazing strategies (Scanlan *et al*. 2013). This bioeconomic modelling package has subsequently been used to evaluate regrowth retention in grazed eucalypt woodlands (Whish *et al*. 2016). Bioeconomic modelling has also been used to study carbon sequestration in a silvopastoral system (Donaghy *et al*. 2010).

Depending on the system concerned, the number of variables and the data available, the bioeconomic models have developed at different levels of integration. These range from a set of loosely coupled sub-models in which the variables from one sub-model are used as driving variables in another (Scanlan *et al*. 2013), through to fully integrated models in which a single set of variables drives the whole model (e.g. Antle and Capalbo 2002). Although the feedback loops and varying spatial and temporal scales provided by many fully integrated models can produce detailed results, these models are typically expensive to develop, and even small errors in the underlying data may be multiplied in final results. Models built on a series of smaller modules may offer more flexibility, be less expensive and require less computing power and skill, particularly if they are built so that only the case relevant modules are required.

The bioeconomic model developed in this study aimed to balance the level of integration with the level of available data. Structured at a farm scale using locally validated relationships for the calculation of carbon sequestration, cattle carrying capacity, and property herd records for cattle value, the model was modified endogenously by the amount of regrowth retention.

Case study region

The Fitzroy Basin region in central Queensland (see Fig. 1) supports ~3000 grazing businesses, which are responsible for the management of 80% of the basin's land area (Christensen and Rodgers 2005). The gross value of agricultural commodities produced in the Fitzroy Basin is over \$1.2 billion annually, with over two-thirds of this value generated from cattle production (ABS 2015). There are three major meat processing centres in the region which employ ~2000 people and process over 3000 head of cattle per day (Swift Australia 2010; Teys 2010). The resulting exposure to proposed carbon policies for agriculture led to the

Fig. 1. Fitzroy Basin region and location of the case study property.

initial interest in understanding the economic implications of carbon trading in this region.

The predominant land types in the Fitzroy Basin are dominated by fertile and productive brigalow forest (*Acacia harpopylla*) and less productive eucalypt woodland land types, much of which have been cleared for agriculture over the last 60–100 years (Christensen and Rodgers 2005). Much of the brigalow forest and eucalypt woodland was cleared by dragging a chain between two bulldozers, resulting in the tree trunks being broken-off, greatly reducing competition with forage plants for water and nutrients. The remaining tree bases and roots generally re-sprout to create regrowth, eventually increasing to levels that impact on pasture production. The relationship between tree regrowth and pasture production follows a tree–grass relationship curve (Scanlan and Burrows 1990; Scanlan 1991). Brigalow, in particular, requires on-going maintenance (re-clearing) to control regrowth and maintain high cattle carrying capacity. Cleared areas of less productive eucalypt woodland will also regrow and, if left untreated, will reduce cattle production capacity over time. This regenerating capability of native, locally adapted tree species along with State government vegetation legislation, provides an opportunity for landholders to choose to retain regrowth and generate carbon offsets on previously cleared grazing land. To produce carbon offsets from regrowth requires that routine regrowth control ceases and regrowth is allowed to grow. Cattle grazing can continue. However, as regrowth increases, forage production declines in line with the tree–grass relationship, thus reducing cattle carrying capacity. Cattle stocking rates must therefore be reduced in line with the reduced cattle carrying capacity to avoid a decline in land condition.

This study used herd, financial and management records from a case study grazing property and experimental data on vegetation and soil carbon stocks to inform management strategies and evaluate relationships used in the bioeconomic modelling.

Key relationships were:

- Tree growth and carbon sequestration,
- Pasture productivity in relation to tree basal area (TBA),
- Cattle carrying capacity in relation to pasture productivity,
- Cattle gross margin (GM) AE^{-1} (AE (adult equivalent) refers to a 450-kg, non-pregnant, non-lactating animal), and
- Carbon income as a function of tree biomass, carbon price, project compliance costs and area of regrowth retained.

Methods

The case study was based on a 2100-ha portion of a property located ~210 km south-west of Rockhampton in Central Queensland, Australia (Fig. 1).

The property is dominated by brigalow land types, with the forest and subsequent regrowth cleared using the chaining method. Small areas of remnant (uncleared) forest have also been retained on the property. The herbicide Tebuthiuron was subsequently used to control regrowth in strips, creating a mosaic of grass areas with little regrowth (~60% of the area) and regrowth areas (~40% of the area). In the herbicide-treated cleared strips, tree root stock is killed, minimising or eliminating further regrowth potential in that area for at least 20 years. Regrowth strips were retained for environmental, financial and perceived livestock productivity benefits. The currently retained regrowth can be cleared under current (2015) government legislation. A rotational grazing system is used to maintain pasture and land condition. The property is used to background[1] heifers, purchased at ~240 kg and sold at 350 kg for entry to a feedlot for finishing and slaughter.

Vegetation and soil

An experimental site was established in a representative area on the property allowing a paired comparison between three vegetation treatments:

- Remnant (uncleared) brigalow forest,
- Retained regrowth,
- Cleared/grass strip following herbicide application.

Woody vegetation carbon was assessed in six 50-m transects for each treatment based on the Transact Recording and Processing System (TRAPS) methodology (Burrows *et al*. 2002). Transect width was 4 m for trees <0.1 m diameter at breast height and 20 m for trees >0.1 m diameter at breast height. Stem location, species and classification of live or dead were recorded, as was stem circumference at 0.3 m height. Woody vegetation biomass was calculated using the allometrics of Butler *et al*. (2012).

Pasture biomass was assessed by visual estimation and by cutting 10 quadrats (0.5×0.5 m) in each treatment using the Botanal technique (Tothill *et al*. 1992).

Soil carbon was assessed in collaboration with the National Soil Carbon Program, regrowth project. Total soil organic carbon was assessed for the 0–0.1, 0–0.3 and 0–0.5 m soil layers. The soil organic carbon sampling and analysis methodology was that as described in Allen *et al*. (2013).

Cattle production

To inform the bioeconomic modelling, the property's financial and livestock records on cattle purchases and sales were accessed. The backgrounding production system has meant that the cattle were weighed regularly (6 weekly to 3 months) to monitor weight gain, and allow turn-off of cattle at the optimal weight. The herd liveweight and liveweight gain records over 4 years were used to calculate average annual productivity (turn-off AE^{-1}) and greenhouse gas emissions AE^{-1} using an Microsoft Excel version of the FarmGAS model (Bray *et al*. 2014) (Table 1). Business benchmarking using Profitprobe™ (Resource Consulting Services 2014) between 2010 and 2014 was used to generate an average annual GM AE^{-1} of \$249. An initial carbon price of \$15 t^{-1} CO_2-e was used as this was close to the average carbon price achieved in the first round of ERF auctions (\$13.96). Annual project costs were assumed to be \$9200 per year (Cohn 2015; Walsh and Cowley 2016).

Bioeconomic model

The bioeconomic model was built within Microsoft Excel using the 'Avoided clearing of native regrowth' and 'Native forest from

[1]The term 'background/backgrounding' is used to refer to a production system where 'purchased' underweight cattle (the terms 'stocker' or 'grower' are sometimes used) are grown to an optimum weight before entering a feedlot or other system for finishing.

Table 1. Bioeconomic model base assumptions

Base model	Base scenario	Sensitivity testing
Discount rate (%)	6%	–
Plot size (ha)	2100	–
Cattle GM ($ AE^{-1})	$249	$187–$311
Include methane emissions (Y/N)	No	–
Clearing method	Herbicide	–
Clearing costs ($ ha^{-1})	$180 and half cattle stocking rate in the clearing year	–
Clearing cycle (years)	15 years after chaining, not required following herbicide	–
Regrowth age at Year 0 (years)	15	5, 10, 15, 20 years
Contract establishment costs ($ $contract^{-1}$)	$0	–
Annual project costs ($ $contract^{-1}$)	$9200	$6900–$11 500
Contract length (years)	20	–
Carbon price ($ t^{-1} CO_2-e)	$15	$5, $10, $15, $20
GHG emissions AE^{-1} $year^{-1}$	2.1 t^{-1} CO_2-e	–

managed regrowth' ERF methodologies as the basis for the scenarios (DoE 2015*b*).

The model compared the 'cattle-only' business-as-usual (BAU) scenario, (cattle production, no carbon sequestration and no requirement to account for carbon emissions) to an alternative 'cattle-carbon' scenario (ending regrowth control on an area of land to allow growth and carbon sequestration over time). The model was designed to allow for the testing of various policy settings including the potential need to account for livestock methane and other on-farm emissions and varying transaction costs, as well as the comparison of alternative baselines to allow for heterogeneity in current practices.

The economic component of the model calculates the stream of annual payments from cattle and carbon production. The present value function can be defined as:

$$I = \sum_{n=1}^{N} [(GM.AE) + h(CP.S_n)](1+r)^{(-n)} \qquad (1)$$

where: N is the decision period in years, GM is the GM per AE for cattle production, AE is the carrying capacity in AE for the enterprise, CP is the carbon price, S is the amount of carbon sequestered (t CO_2-e ha^{-1}), h is the area of the enterprise (hectares), and r is the discount rate.

The regrowth and grass productivity functions are shown in Table 2 (and justified in the Results). The regrowth growth rate relationship was based on the site measurements and compared with the Full Carbon Accounting Model (FullCAM) prediction for carbon sequestration using the regrowth methodology (DoE 2015*c*).

The pasture productivity to TBA relationship was derived from GRASP modelling for the brigalow scrub land type at Rolleston as archived in the Stocktake™ database (DPI and F 2004), and modified to more closely fit the on-site pasture measurements and previous research on this land type (Scanlan 1991; Donaghy *et al.* 2010).

Table 2. Regrowth, grass production and carrying capacity functions
Where: x = age of regrowth; t = tree basal area (m^2 ha^{-1}); g = grass production (t ha^{-1}); u = grass utilisation rate (%); i = intake (kg day^{-1}); S_n = carbon sequestration in year n

	Units	Equation	
Regrowth basal area (t)	(m^2 ha^{-1})	$\boldsymbol{t = 2.2746 ln(x) - 0.3045x}$	2
Grass production (g)	(t ha^{-1})	$\boldsymbol{g = 6000 * EXP(-0.301t)}$	3
Carrying capacity (cc)	(AE ha^{-1})	$\mathbf{CC} = \dfrac{\boldsymbol{g.u}}{\boldsymbol{i.365}}$	4
Regrowth carbon stocks			
Above ground	t^{-1} CO_2-e ha^{-1}	$\boldsymbol{C_a} = (3.5\boldsymbol{t})\left[\mathbf{0.5}\left(\dfrac{\mathbf{44}}{\mathbf{12}}\right)\right]$	5
Below ground	t^{-1} CO_2-e ha^{-1}	$\boldsymbol{C_b} = (3.5\boldsymbol{t} \times 0.4)\left[\mathbf{0.5}\left(\dfrac{\mathbf{44}}{\mathbf{12}}\right)\right]$	6
Carbon sequestration ($\boldsymbol{S_n}$) in year n	t^{-1} CO_2-e ha^{-1}	$S_n = (C_{an} + C_{bn}) - (C_{an-1} + C_{bn-1})$	7

Cattle carrying capacity was calculated in terms of the number of AE as a function of grass production; therefore, no reduction in individual animal performance was assumed.

Equations 2–7 in Table 2 define the conversions from TBA to carbon sequestration. The development of the model in this format allows evaluation of the effects of the age of regrowth and type of regrowth control on cattle and carbon production.

The discount rate used was 6%. Sensitivity analysis was conducted on the discount rate however the results did not differ substantially, thus are not reported.

The cost of carbon sequestration is the opportunity cost of the alternative land use (in this case cattle production) plus the transaction costs of achieving additional carbon sequestration and participating in a carbon-trading program. The cost effectiveness of carbon sequestration is the present value of the cost of sequestration.

Using this model, net present value (NPV) was calculated for the enterprise under a BAU scenario and for each alternate scenario.

Three scenarios were evaluated:

Scenario 1 'cattle-only' is the BAU cattle production enterprise assuming the whole property is initially covered by 15-year-old regrowth.

Scenario 2 'cattle-carbon' is the option to establish an ERF (carbon) project by retaining regrowth on 100% of the property.

Scenario 3 'cattle-carbon' is the option to establish an ERF (carbon) project by retaining regrowth on different proportions of land (25%, 50% and 75% of regrowth retained).

Sensitivity analyses were undertaken on:

– Carbon price,
– Cattle GM,
– Severity of the tree grass relationship,
– Age of regrowth at start of project, and
– Annual carbon project costs.

Results

Justification of functions used in the bioeconomic modelling

Cattle methane emissions were estimated based on 4 years of landholder livestock records. Average livestock emissions per AE were 2.1 t^{-1} CO_2-e AE^{-1} $year^{-1}$.

The TBA growth function was based on the assumption that the remnant vegetation was 80 years old, and the cleared strip was recently re-cleared (Fig. 2).

Using the TBA equation (Eqn 2) underestimated the carbon stocks compared with the FullCAM model (Fig. 3). As the former was more conservative, it was used in the modelling. However, to evaluate the impact of faster rates of regrowth, a TBA equation was derived from the FullCAM relationship and used to evaluate sensitivity of the NPV.

Pasture biomass at each sampling date declined strongly with increasing TBA (Fig. 4). The generally dry climatic conditions resulted in lower maximum pasture biomass.

The modelled pasture growth for the brigalow scrub land type was extracted from Stocktake™ and modified to reflect the more severe negative impact on pasture growth at high woody plant basal area (Figs 4 and 5; Scanlan 1991). A less severe 'alternate' tree grass relationship was also used to assess sensitivity to the tree–grass relationship.

No differences were found in soil organic carbon between the cleared, regrowth and remnant vegetation treatments (Fig. 6), and soil carbon was not considered further in the bioeconomic modelling. Based on these results, it was determined that sequestering soil organic carbon was unlikely to be a viable means of producing tradeable carbon offsets on this land type with regrowth retention.

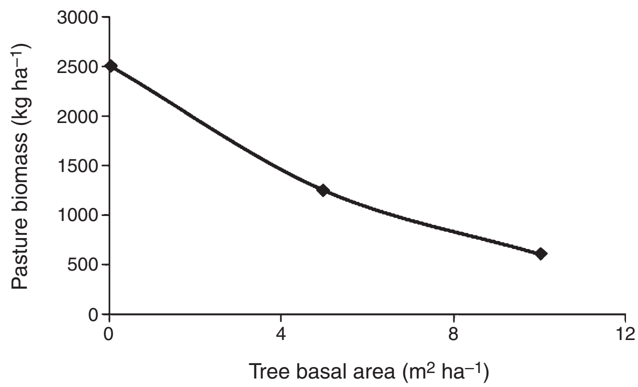

Fig. 4. Relationship between pasture biomass and tree basal area for one sampling date at the study site.

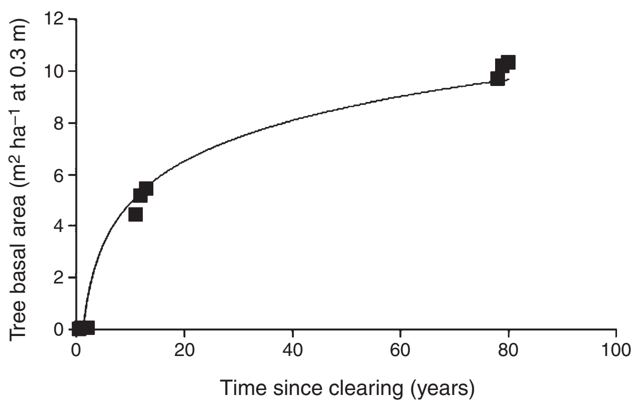

Fig. 2. Relationship between time since clearing and tree basal area of regrowth at the study site. Remnant vegetation was assumed to be 80 years old.

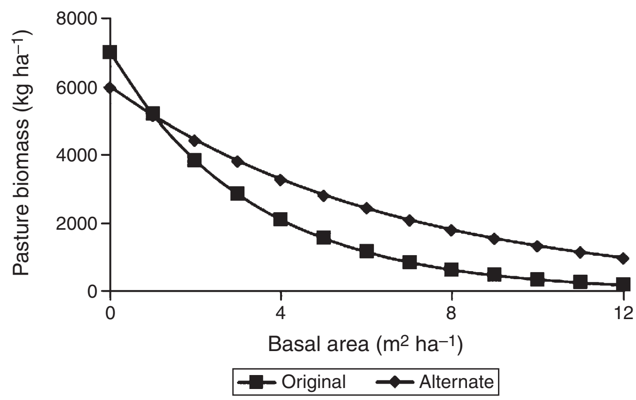

Fig. 5. Tree grass relationship used in the bioeconomic modelling (original) and the relationship used to test sensitivity to the tree grass relationship (alternate).

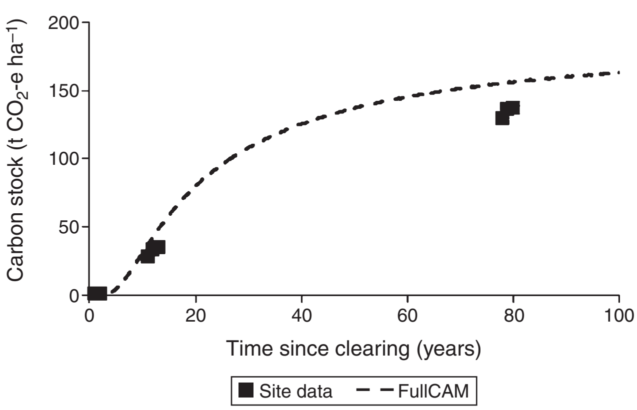

Fig. 3. Relationship between tree carbon stock and time since clearing. The dashed line depicts FullCAM modelled growth and squares are the site data. Remnant vegetation was assumed to be 80 years old.

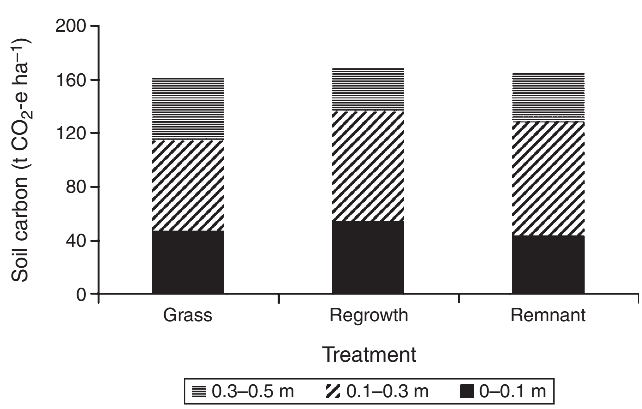

Fig. 6. Soil organic carbon stock for cleared grassland, regrowth and remnant vegetation sites.

Bioeconomic modelling results

Scenario 1 – cattle-only

Based on actual data from the existing cattle-only system, and assuming constant income and costs, the total discounted net income over 20 years would be \$4.98 million (cattle income minus regrowth control costs) (Table 3). However, the NPV was only \$2.8 million due to the high upfront costs of clearing the 15-year-old regrowth in the first year.

Scenario 2 – cattle-carbon, 100% regrowth retained

For the cattle-carbon scenario, assuming a carbon price of \$15 t^{-1} CO_2-e, the total amount of carbon to be traded over 20 years was 233 736 t CO_2-e, of which 124 692 t CO_2-e was present in the regrowth at the start of the project. Over 20 years average net carbon income (carbon income minus project costs) was \$175 302 per year, and average cattle GM income \$38 548 per year (Table 4). However, the NPV was \$3.26 million, which was 16% higher than the cattle-only scenario.

It should be noted that the key driver behind the relative profitability of the cattle-carbon scenario was the ability to sell offsets from avoided deforestation (carbon in the 15-year-old regrowth) at the beginning of the project. If the relevant government policy does not allow the sale of avoided deforestation offsets, the NPV for the carbon and cattle scenario reduces to \$1.39 million, less than half the NPV of the cattle-only scenario.

Table 3. Scenario 1 Cattle-only. Assumptions and financial results

Cattle-only (0% regrowth retained)	Year 0	Years 1–19	Total over 20 years
Number of hectares	2100	2100	–
AE	551	1103	21 508
GM per AE	\$249	\$249	–
Cattle GM per year	\$137 199	\$274 647	\$5 355 492
Regrowth control costs	\$378 000	\$0	–
Net income per year	(\$240 801)	\$274 647	\$4 977 492
Net present value	–	–	\$2 823 742

Scenario 3 – cattle-carbon, retaining regrowth at different proportions

In addition to deciding whether or not to engage in carbon trading, a landholder must decide on the optimal amount of land to enter into the carbon trading project. To evaluate this, regrowth retention on 25%, 50% and 75% of the land area was evaluated. The level of retention affected the NPV in three ways: through the amount of carbon available to trade, the cost of clearing, and the cattle carrying capacity. As the area of regrowth retained was reduced, the NPV declined and the breakeven carbon price increased (Table 5). The difference in net cash flows is depicted in Fig. 7. The retention of 25% regrowth, offset clearing costs on the other 75% of the area in Year 1 (preventing negative cashflow) when the carbon price is \$15 t^{-1} CO_2-e.

Table 4. Scenario 2 Cattle-carbon. Assumptions and financial results
Carbon price was \$15 t^{-1} CO_2-e

Cattle-carbon (100% regrowth retained)	
Number of hectares	2100
Total cattle income over 20-year analysis period	\$742 269
Annual carbon monitoring cost per year	\$9200
Regrowth control cost per year	\$0
Total carbon sequestered over analysis period	233 736
Total carbon income	\$3 506 047
Net income per year	\$1 888 075
Net present value	\$3 233 826

Table 5. Impact of variation in the amount of regrowth retained on net present value (NPV) and breakeven carbon price

% regrowth retained	NPV (\$15 t^{-1} CO_2-e)	Breakeven price (\$15 t^{-1} CO_2-e)
100%	\$3 260 718	\$12.72
75%	\$3 104 005	\$13.05
50%	\$2 973 735	\$13.43
25%	\$2 843 351	\$14.59
0% Cattle-only	\$2 823 742	NA

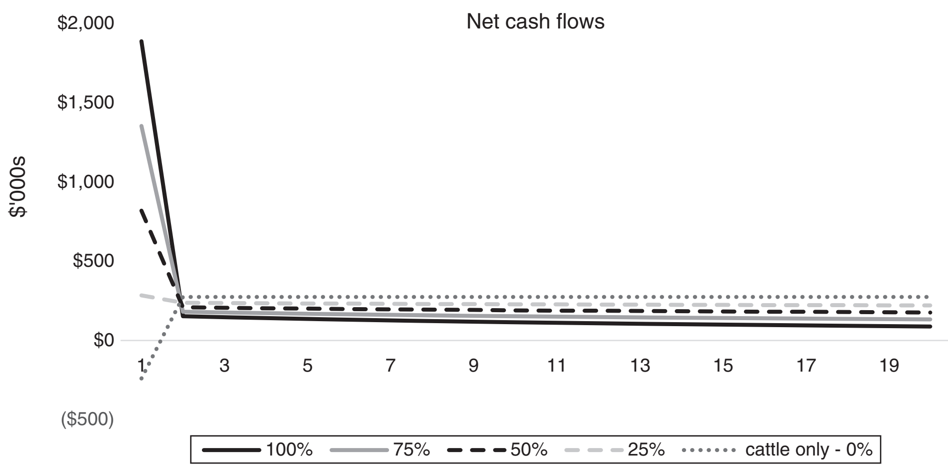

Fig. 7. Projected net annual cash flow for the five levels of regrowth retention modelled.

Sensitivity analysis

Sensitivity analysis was conducted on carbon price, cattle GM, age of regrowth at start of project, severity of the tree–grass relationship and annual project transaction costs.

Carbon price

The carbon price was the variable which was likely to have the greatest volatility in these scenarios. The results of a range of carbon prices are shown in Table 6. The breakeven price between the cattle-only (0% regrowth retained) and cattle-carbon (100% regrowth retained) scenario was approximately $\$12.72\,t^{-1}$ CO_2-e, which was close to the average price achieved by the first round of ERF auctions ($13.96). The breakeven carbon price was relatively low compared with other estimates of the relative profitability of carbon trading conducted for cropping and sheep enterprises (Kragt *et al*. 2012; Nayar and Froese 2013; Alcock *et al*. 2015), but not substantially lower than the $\$18\,t^{-1}$ CO_2-e carbon price required for economic viability for integrated farm forestry on marginal land in temperate Australia (Paul *et al*. 2013). As discussed in the section above, a key driver of the profitability of cattle-carbon is the sale of offsets from avoided deforestation. Without these offsets the breakeven price increases to ~$\$36.50\,t^{-1}$ CO_2-e.

Cattle gross margin

Cattle prices, input costs and production levels vary between years and between cattle enterprises (McLean *et al*. 2014). The effect of higher or lower cattle GM (combination of cattle price and input costs) were examined. The NPV for the cattle-only and cattle-carbon scenarios were estimated by applying GM at 75% and 125% of the base GM. As shown in Table 7, the cattle-carbon scenario had a higher NPV for the base GM ($\$249\ AE^{-1}$) and the reduced GM ($\$187\ AE^{-1}$). However, the cattle-only scenario NPV was higher than the cattle-carbon scenario when the cattle GM was 25% above the base GM ($\$311\ AE^{-1}$). At the higher GM, the breakeven carbon price increases by 27% to ~$\$16.25\,t^{-1}$ CO_2-e.

Table 6. Impact of variation in carbon price on net present value (NPV)

Carbon price	NPV
$5	$1 343 879
$10	$2 302 299
NA (Cattle-only)	$2 823 742
$15	$3 260 718
$20	$4 219 138

Table 7. Impact of change in cattle GM on net present value and breakeven carbon price

Cattle GM ($\$\ AE^{-1}$)	Cattle-only	Cattle-carbon ($\$15\,t^{-1}$ CO_2-e)	Breakeven price ($\$15\,t^{-1}$ CO_2-e)
$187 (75%)	$2 023 307	$3 116 221	$9.20
$249 (100%)	$2 823 742	$3 233 826	$12.72
$311 (125%)	$3 624 178	$3 351 432	$16.25

Age of regrowth

The age of the regrowth at the start of the scenarios had a significant impact on the relative value of each alternative scenario, as it determined the timing of both regrowth clearing for the cattle-only scenario and the value of upfront carbon sales in the standing regrowth for the cattle-carbon scenario. As the age of regrowth increased from 5 to 20 years, the NPV for the cattle-only option decreased. This was due to regrowth control occurring earlier in the analysis period with older regrowth and thus the significant control cost was discounted less (Table 8). Also, the cattle carrying capacity was lower earlier in the analysis period for older regrowth, which also contributed to reduced NPV. In comparison, as the age of regrowth increases so does the NPV for the cattle-carbon scenario. This was a consequence of the higher value of avoided deforestation offsets which are available for sale at the beginning of the analysis period. If the regrowth was 10 years old or less at the start of the analysis, the cattle-only scenario had a higher NPV.

These results highlight how much the supply and profitability of generating carbon offsets is likely to vary both within and between properties.

Tree–grass relationship

The data used to estimate the tree–grass relationship were based on modelling, literature and experimental data for the case study location and land type (Figs 4 and 5). A less severe alternate tree–grass relationship was evaluated to test sensitivity of the relationship (Fig. 5). Using this relationship, the NPV for the cattle-only scenario was reduced by more than $300 000 (Table 9), because the maximum grass production (and cattle carrying capacity) were lower for the alternate function at the basal area determined by the clearing regime ($0.3\,m^2\,ha^{-1}$) (Fig. 8). In comparison, the NPV for the cattle-carbon scenario increased by more than $650 000 because the grass production for the given starting basal area ($5.7\,m^2\,ha^{-1}$) was higher than the original function, and because grass production declined more slowly as regrowth increased, thus increasing cattle carrying capacity and productivity.

Table 8. Impact of age of regrowth at start of analysis period on net present value and breakeven carbon price

	5 years	10 years	15 years	20 years
Cattle-only	$3 051 367	$2 954 017	$2 608 664	$2 608 664
Cattle-carbon	$2 585 945	$2 896 216	$3 233 826	$3 555 815
Breakeven price ($\$15\,t^{-1}$ CO_2-e)	$18.20	$15.10	$12.72	$11.55

Table 9. Impact of an alternate tree–grass relationships on net present value and breakeven carbon price

	Original	Alternate
Cattle-only	$2 823 742	$2 495 842
Cattle-carbon	$3 260 718	$3 918 721
Breakeven price ($\$15\,t^{-1}$ CO_2-e)	$12.72	$7.60

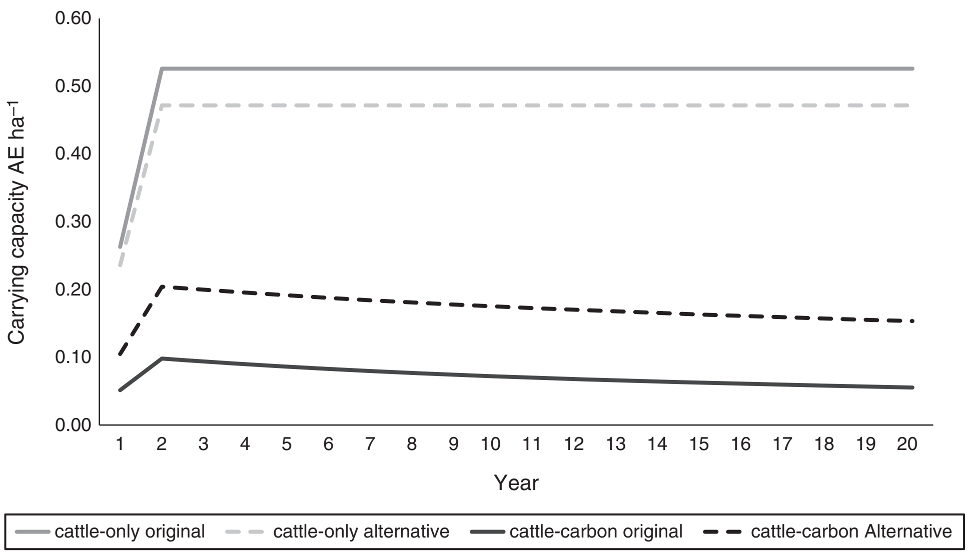

Fig. 8. Difference in livestock carrying capacity over time with change in the tree–grass relationship (original and alternate) for the cattle-only and cattle-carbon scenarios.

Table 10. Impact of variation in carbon project costs on net present value (NPV) and breakeven carbon price

	NPV (\$15 t^{-1} CO_2-e)	Breakeven carbon price
Cattle-only	\$2 823 742	–
\$6900 (75%)	\$3 261 790	\$12.71
\$9200 (100%)	\$3 233 826	\$12.86
\$11 500 (125%)	\$3 205 863	\$13.06

Annual carbon project costs

Estimating the costs of establishing and maintaining a carbon project is extremely difficult because of the recent establishment of the ERF scheme and the lack of data. However, carbon project costs have been estimated (Cohn 2015; Walsh and Cowley 2016). Over time the costs could reduce as measurement protocols and technology become more efficient. However, even if transaction costs are only 75% of estimated current levels, the NPV and breakeven carbon price does not materially change (Table 10).

Discussion

This study was designed to investigate the trade-offs at the property scale between producing cattle or retaining regrowth for carbon sequestration. The results showed that ceasing vegetation regrowth clearing in favour of producing carbon offsets produced a higher NPV over 20 years than the existing cattle enterprise, at carbon prices which were close to market levels in 2015 (~\$13 t^{-1} CO_2-e). Sensitivity analysis evaluated key variables, which determined the relative profitability of cattle-carbon and cattle-only enterprises. The variables in order of impact were: the carbon price, the GM of cattle production, age of regrowth at the start of the project, severity of the tree–grass relationship and to a lesser extent the cost of carbon project administration, compliance and monitoring. Carbon price and carbon project costs are independent of the existing cattle enterprise and chosen land parcel. However, the other variables vary both within and between land parcels, potentially having an impact on carbon project land parcel selection. In particular, the key determinant of the opportunity cost of the cattle enterprise is the relationship between TBA and grass production which drives cattle carrying capacity and cattle enterprise productivity.

Tree–grass relationship

The tree–grass relationship varies between and within land types depending on rainfall, topography and land management (Scanlan 2002). The case study land type had a strongly negative relationship between TBA and grass production as demonstrated by field and modelled data (Figs 4 and 5), resulting in a significant opportunity cost to cattle production before the benefits of retaining regrowth were realised. Land types with a less severe negative relationship, for example, eucalypt woodlands (Scanlan and Burrows 1990; Donaghy *et al*. 2010) may have a lower opportunity cost. The importance of the tree–grass relationship was further highlighted by the sensitivity analysis. The impact of the less severe alternate tree–grass relationship was that the combined cattle and carbon income improved by 20% as a result of higher livestock returns for the same tree growth.

The tree–grass relationship depicts that as the TBA increased, grass production and therefore cattle carrying capacity declined. If cattle numbers are not reduced in line with the decline in carrying capacity, land condition and individual livestock productivity will decline, reducing the sustainability of the cattle enterprise and leading to other off-farm impacts such as poor water quality (Bartley *et al*. 2010; Star *et al*. 2013). Considered selection of land types or areas of lower cattle productivity (e.g. rocky hills) and high tree growth will also help minimise the opportunity costs of retaining regrowth, and the likelihood of negative impact on land condition on many properties.

Age of regrowth

Age of regrowth at the beginning of the analysis period also had a significant impact on the NPV, with lower income for the cattle-only scenario and old regrowth caused by the upfront cost of clearing. In comparison, the cattle-carbon scenario with old regrowth produced higher net returns, because of the ability to sell the initial carbon stock at the start of the analysis and avoidance of the clearing cost (Table 8). The decision to retain young regrowth for carbon credits had a lower NPV than the cattle-only (0% regrowth retained) scenario. As a result of these interactions, it is likely that individual landholders will have some areas and paddocks more profitable for generation of carbon offsets at any point in time than other areas, depending on past clearing history and land type.

On both landholder and policymaker levels, these results imply that analysis of the potential capacity of agricultural land to supply profitable carbon offsets should be done at a much smaller scale than the land type or region.

Commodity prices

The breakeven carbon price identified in this analysis (~\$13; Table 6) is similar to the average market price at the first two ERF auctions (\$13.12 t^{-1} CO_2-e – Clean Energy Regulator 2015). This similarity indicates a high project risk if carbon price declines or cattle prices rise substantially. In this analysis, a 25% increase in cattle GM resulted in a 27% increase in the breakeven carbon price. This would significantly reduce the competitiveness of carbon offsets against cattle production. GM for cattle production have historically remained fairly static in Australia and are trending down in real terms (McLean *et al*. 2014). However, the Australian and global cattle herds are currently at record low levels with corresponding record high prices due to increasing demand (Thomas 2015). If these patterns of supply and demand in the global beef market continue, significant cattle price increases could occur in the medium term, resulting in an increase in cattle GM. The number of landholders willing to supply carbon offsets at current carbon prices could fall if that would lock them out of potential increased returns from cattle production.

Carbon project transaction costs

Compared with other variables, carbon project transaction costs were found to be less influential on the trade-off between cattle and carbon enterprises. However, if carbon offsets from extensive rangelands are to remain competitive with other offset sources, ways to minimise the costs will be required through using technology for verification and auditing (e.g. satellite imagery) and/or aggregation with other carbon projects to share the costs. Importantly, this analysis assumed fixed transaction costs for the project. However, if transaction costs are variable on a per-hectare or per-t CO_2-e basis, the scale of the project is likely to have a significant impact on relative returns.

Bioeconomic modelling approach

The advantage of using bioeconomic modelling to construct this analysis is the ability to conduct sensitivity analysis on all variables over any desired range. Although the model does not allow for dynamic simulations with interacting variables, its simplicity does allow for easy repetition across alternate scenarios or application to specific case studies. While this analysis was constructed at the property scale, the model could easily be scaled up to the regional scale (with consideration to variation within the chosen area in GM and so on) or down to the paddock level.

The results from the bioeconomic modelling case study approach provide evidence of relative advantage for landholders considering major changes in their production system. Along with trialability, relative advantage has consistently been shown to be a necessary but not sufficient determinant of adoption of practice changes among agricultural landholders (Pannell and Vanclay 2011). Many other factors including, but not limited to, landholders' risk profiles, attitude to environmental conservation, age, level of education and size of enterprise have also been shown to influence adoption (Pannell and Vanclay 2011). As a result, landholders are likely to demand a price greater than breakeven to adopt practices which enable them to trade carbon offsets, with the magnitude of the gap further influenced by the length of the contract and the amount of monitoring required (Gowen 2014).

Conclusion

This study demonstrated that retaining regrowth to produce carbon offsets may be profitable at carbon prices close to current (2015) market levels. Compared with other sources of agricultural offsets, retained regrowth could be a much more cost-effective source of carbon offsets. However, the breakeven carbon price varies substantially depending on policy rules, GM of the existing enterprise and regrowth condition at the commencement of the carbon project. Based on these results, landholders would be wise to conduct their own specific analysis before agreeing to any carbon project, and policy makers should exercise caution when estimating the potential quantity of carbon offsets likely to be supplied by landholders under current market conditions.

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