Scenario analysis of alternative vegetation management options on the greenhouse gas budget of two grazing businesses in north-eastern Australia

S. G. Bray[A,C] *and R. Golden*[B]

[A]Department of Primary Industries and Fisheries (DPI&F), PO Box 6014, Rockhampton MC, Qld 4702, Australia.
[B]'Potters Flat', Wandoan, Qld 4419, Australia.
[C]Corresponding author. Email: steven.bray@dpi.qld.gov.au

Abstract. The emerging carbon economy will have a major impact on grazing businesses because of significant livestock methane and land-use change emissions. Livestock methane emissions alone account for ~11% of Australia's reported greenhouse gas emissions. Grazing businesses need to develop an understanding of their greenhouse gas impact and be able to assess the impact of alternative management options. This paper attempts to generate a greenhouse gas budget for two scenarios using a spread sheet model.

The first scenario was based on one land-type '20-year-old brigalow regrowth' in the brigalow bioregion of southern-central Queensland. The 50 year analysis demonstrated the substantially different greenhouse gas outcomes and livestock carrying capacity for three alternative regrowth management options: retain regrowth (sequester 71.5 t carbon dioxide equivalents per hectare, CO_2-e/ha), clear all regrowth (emit 42.8 t CO_2-e/ha) and clear regrowth strips (emit 5.8 t CO_2-e/ha). The second scenario was based on a 'remnant eucalypt savanna-woodland' land type in the Einasleigh Uplands bioregion of north Queensland. The four alternative vegetation management options were: retain current woodland structure (emit 7.4 t CO_2-e/ha), allow woodland to thicken increasing tree basal area (sequester 20.7 t CO_2-e/ha), thin trees less than 10 cm diameter (emit 8.9 t CO_2-e/ha), and thin trees <20 cm diameter (emit 12.4 t CO_2-e/ha).

Significant assumptions were required to complete the budgets due to gaps in current knowledge on the response of woody vegetation, soil carbon and non-CO_2 soil emissions to management options and land-type at the property scale. The analyses indicate that there is scope for grazing businesses to choose alternative management options to influence their greenhouse gas budget. However, a key assumption is that accumulation of carbon or avoidance of emissions somewhere on a grazing business (e.g. in woody vegetation or soil) will be recognised as an offset for emissions elsewhere in the business (e.g. livestock methane). This issue will be a challenge for livestock industries and policy makers to work through in the coming years.

Additional keywords: carbon, livestock methane, regrowth, savanna woodland, soil.

Introduction

Grazing businesses located in savanna woodlands are responsible for managing a massive carbon store in the soil and vegetation. Globally the soil carbon pool in tropical savannas (2250 Mha) is estimated at 968 Gt CO_2-e (to 1 m depth) while the vegetation contains 242 Gt CO_2-e (IPCC 2000). An assessment of 13 'brigalow' sites in the Brigalow bioregion of Queensland (Harms and Dalal 2003) indicated a mean soil carbon stock of 330 t CO_2-e/ha (to 1 m depth) and an aboveground vegetation carbon stock of 250 t CO_2-e/ha in remnant (uncleared) woodland vegetation. This equates to a carbon stock of 1.5 Mt CO_2-e for a 4000 ha property with 20% remnant vegetation. By comparison, 10 'eucalypt dominated' sites in the lower productivity Einasleigh Uplands bioregion of north Queensland (Bray *et al*. 2006) indicated a mean soil carbon stock of 213 t CO_2-e/ha (to 1 m depth) and an aboveground vegetation carbon stock of 150 t CO_2-e/ha in remnant savanna woodland vegetation, equating to a carbon stock of 6.7 Mt CO_2-e for a typical 20 000 ha property with 80% remnant vegetation.

Apart from managing significant carbon stocks in soils and vegetation, grazing businesses are also responsible for significant greenhouse gas emissions, primarily through livestock methane emissions, land use change (tree clearing), fuel and energy use. Australia's reported greenhouse account for 2005 indicates that livestock methane emissions account for 11% (62 Mt CO_2-e) of emissions, and woody vegetation clearing (primarily for grazing) accounts for 9.5% (53.3 Mt CO_2-e) of emissions (AGO 2007). Land use change emissions were significantly reduced from previous years following the introduction of the *Vegetation Management Act* (1999) in Queensland, which has effectively stopped broad-scale land clearing. The livestock grazing industry is regarded as

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greenhouse gas emissions intensive because the industry accounts for significant reported emissions, although it only contributes ~1% to Australia's gross domestic product (ABS 2005).

Is there any scope for grazing businesses to mitigate their emissions, to choose less greenhouse gas intensive development options or to differentiate their business as having an improved greenhouse outcome, given the context of Australia's reported greenhouse gas impact of grazing industries? One possible tool grazing businesses could utilise is a property-scale greenhouse gas budget. This would assess all major carbon/greenhouse gas stocks, fluxes and emissions over time and enable prediction of the change in greenhouse gas impact in response to different management options.

Some management options which may modify their greenhouse gas impact are available to grazing businesses. These include managing regrowth vegetation; property development to increase livestock carrying capacity including thinning 'thickened' remnant vegetation [within the *Vegetation Management Act* (1999) guidelines]; grazing management to increase soil carbon and soil health; use of best practice nutrition and genetics to improve productivity per unit of livestock methane produced; and, improving fuel and energy use efficiency.

Current limitations to undertaking a property-scale greenhouse gas budget are the significant gaps in present knowledge, particularly in regards to the response of carbon stocks and fluxes to management options along with their interaction with land types and land condition at the property scale. Initial predictions will require a significant number of assumptions until property-scale data and scientific knowledge improves over time.

This paper utilises current land manager and scientific knowledge to assess the greenhouse gas impact of alternative woody vegetation management options for two major land types in Queensland; '20-year-old brigalow regrowth' and 'remnant eucalypt savanna-woodland'. The management options assessed for Scenario 1 '20-year-old brigalow regrowth' include: (1) retain regrowth, (2) clear all regrowth, and (3) clear regrowth in strips. The management options assessed for Scenario 2 'remnant eucalypt savanna-woodland' include: (1) retain current woodland structure, (2) allow woodland to thicken (increase in tree basal area), (3) thin trees <10 cm diameter at breast height (DBH), and (4) thin trees <20 cm DBH. The impact of the management options on livestock productivity (adult equivalent, AE, carrying capacity) is modelled. Gaps in current knowledge and assumptions required to complete the greenhouse gas budgets are documented. This exercise focuses on development of a realistic 'property-scale' greenhouse gas budget to aid in understanding the impact of management decisions. This analysis is not designed to meet the criteria of eligibility, additionality, permanence and leakage of a contracted 'mitigation project' or rules of the Australian Carbon Pollution Reduction Scheme, nor is the analysis designed to assess the economic return of management decisions which include a price for carbon storage or emission.

Materials and methods

Fourteen significant carbon stocks and greenhouse gas emissions for a grazing business were considered in an analysis of management options for two different land-type scenarios in northern Australia: twenty-year-old brigalow (*Acacia harpophylla* F.Muell. ex Benth.) regrowth (20YBR) and remnant eucalypt (dominated by *Eucalyptus crebra* F.Muell., *Eucalyptus melanophloia* F.Muell., and *Eucalyptus brownii* Maiden & Cambage) savanna woodland (RESW). The analysis used an annual time-step over a 50-year period. Assumptions and data used to calculate individual carbon stocks and greenhouse gas emissions for the management options in each scenario are presented in Table 1. An Excel spreadsheet was used to model the combined impact of individual carbon stocks and greenhouse gas emissions.

Scenario 1: Twenty-year-old brigalow regrowth (20YBR)

The analysis is based on data and experience from a 4000 ha property in the brigalow bioregion of southern-central Queensland. The region has been grazed since the mid-1800s. However, intensive development began in the 1940s with ringbarking of timber, followed by pulling of the brigalow scrub with bulldozers and chain in the 1960s and '80s. Blade ploughing is the current preferred timber control method for brigalow regrowth. Retention of regrowth strips has been trialled on a small area. Grazing intensity on the property is moderate to conservative for the region. Rotational grazing has been implemented over the last 10 years with the objective of improving grazing management and land condition outcomes.

Twenty-year-old brigalow regrowth (basal area ~3 m^2/ha at 30 cm height) is the largest 'land type' covering a quarter of the property (~1000 ha). Over a simulated 50-year period the impact of three management options were assessed:

(1) retain regrowth – allow regrowth to continue to grow;
(2) clear all regrowth – blade plough in 2nd and 31st years; and
(3) clear regrowth strips – blade plough in 2nd and 31st years (20 m cleared, 12 m retained).

Table 2 lists tree basal area and livestock carrying capacity values for different regrowth stages which were generated by field measurement and land manager experience. Grazing productivity within the retained strips was assumed to remain 0.2 AE/ha based on land manager experience and the work by McKeon *et al*. (2008) on the benefits of tree strips. Tree basal area and grazing productivity was assumed to change linearly between the states described in Table 2.

Scenario 2: Remnant eucalypt savanna-woodland (RESW)

The analysis is based on a generic remnant eucalypt savanna-woodland land type in the Einasleigh Uplands bioregion of north Queensland. Soil carbon, tree basal area and tree size class data were generated from 10 field sites in the region (Bray *et al*. 2006).

Over a simulated 50 year period the impact of four management options were assessed:

(1) retain current woodland structure;
(2) allow woodland to thicken (increase in tree basal area);
(3) thin trees <10 cm DBH every 20 years from year 2; and
(4) thin trees <20 cm DBH every 25 years from year 2.

The rate of thickening (increase in stand tree basal area) used in the 'allow woodland to thicken' management option was 0.045 m^2/ha.year at 30 cm height, which was within the range of estimates of woodland thickening in the region assessed from

Table 1. Assumptions and data source for individual carbon stocks and greenhouse gas emissions assessed for two Queensland grazing business scenarios

20YBR, Scenario 1: 20-year-old brigalow regrowth; RESW, Scenario 2: remnant eucalypt savanna-woodland

No.	Stock or flux	Assumptions and data source
1	Live tree biomass	Aboveground biomass change assessed. Belowground biomass assumed no change. 20YBR: See Table 2 for tree basal area and time since clearing assumptions. Biomass estimates were based the regrowth data by Scanlan (1991). RESW: See Table 3 for tree basal area and impact of thinning assumptions. Initial tree basal area and tree size class were generated from 10 sites in the Einasleigh Uplands (Bray *et al*. 2006). Biomass estimates are based on the allometrics of (Burrows *et al*. 2000). Following thinning trees <10 cm the stand regrows linearly in 20 years and following thinning trees <20 cm the stand regrows linearly in 25 years.
2	Dead standing tree biomass	20YBR: Assumed zero stock following the original pulling. RESW: Assumed remains static (15 t CO_2-e/ha). Value generated from 10 sites in the Einasleigh Uplands (Bray *et al*. 2006).
3	Coarse woody debris (CWD)	20YBR: Stock unknown from original pulling (stick raked into unburnt piles), assumed zero and no change. RESW: Stock unknown, assumed zero and no change.
4	Woody clearing debris	20YBR: Assessed. Assume decays linearly over 15 years based on land manager observations. RESW: Assessed. Assume decays linearly over 15 years.
5 and 6	Forage biomass and litter biomass	20YBR: Assumed forage and litter biomass combined remained 7.3 t CO_2-e/ha. RESW: Assumed forage and litter biomass combined remained 4.4 t CO_2-e/ha.
7	Soil carbon stock to 1m	Assumed no change in response to management options due to lack of data. 20YBR: Soil carbon 475 t CO_2-e/ha (average of site 34 and 35 on actual property; Harms and Dalal 2003). RESW: Soil carbon 213 t CO_2-e/ha, average of 10 sites in the Einasleigh Uplands (Bray *et al*. 2006).
8	Livestock carbon and livestock off-take	20YBR and RESW Assessed livestock carbon stock based on carrying capacity. 1 AE = 450 kg, 35% DM, 50% C. Off-take not assessed.
9	Livestock methane emissions	20YBR and RESW: Assessed, based on livestock carrying capacity and cumulative. 2.9 t CO_2-e/AE.year calculated from Kennedy *et al*. (2007).
10	Soil and paddock manure non-CO_2 emissions	20YBR and RESW: Assumed zero t CO_2-e/ha. Assumed no change in response management options due to lack of data.
11	Savanna burning	20YBR: Assumed no burning. RESW: Assessed. 0.1 t CO_2-e/ha/fire using the methodology outlined in (DCC 2008) (fuel mass of 1.5 t DM/ha). Assumed no change in livestock numbers due to fire.
12	Livestock transport and processing emissions	20YBR and RESW: Not assessed post farm-gate. On-farm fuel use included in 'general property energy emissions'.
13	Clearing fuel emissions	Assessed, based on land manager data, cumulative. 20YBR: 0.158 t CO_2-e/ha for each clearing event. RESW: 0.08 t CO_2-e/ha for each thinning event (assumed half blade ploughing emissions).
14	General property energy emissions (fuel, electricity)	20YBR and RESW: Assessed, based on land manager data, cumulative. 0.0088 t CO_2-e/ha.year.

Table 2. Tree basal area and livestock carrying capacity values for different regrowth states in Scenario 1: 20-year-old brigalow regrowth

	Tree basal area at 30 cm height (m^2/ha)	Livestock carrying capacity (AE/ha)
Cleared brigalow	0.25	0.4
20-year-old pulled regrowth	3	0.2
40-year-old pulled regrowth	8	0.05
60-year-old pulled regrowth	13	0.0
30-year-old blade ploughed regrowth	3	0.2

ground-based monitoring and aerial photography analysis (Burrows *et al*. 2002; Fensham *et al*. 2003, 2007). The thinning trees <10 and <20 cm DBH cut-off values match the thinning conditions on actual development permits (required by law in Queensland) which vary depending on region. The permits also have several other conditions including the minimum number of stems that must be retained per hectare and a requirement that a range of tree size classes must be retained. Using the tree size data all trees <10 or <20 cm DBH were assumed to be cleared in this analysis. We have assumed that 're-thinning' will be permitted and that the stand will regrow linearly in 20 years following thinning trees <10 cm and in 25 years following thinning trees <20 cm. This equates to a rate of stand growth following thinning of 0.064 and 0.143 m^2/ha.year at 30 cm height for the <10 and <20 cm DBH thinning options, respectively. Faster growth rates following thinning are expected based on work by Back *et al*. (2009). Individual tree and stand biomass estimates were calculated using the allometrics of Burrows *et al*. (2000, 2002).

The Stocktake feed budgeting package (DPI&F 2004) was used to estimate livestock carrying capacity in response to changed tree basal area (Table 3). Fire frequency (savanna burning) was assumed to be one fire every 10 years (starting in year 5) in the 'retain current woodland structure' management option (this frequency was assumed to be sufficient to maintain the current woodland structure) and one fire every 20 years (starting in year 5) for the other management options. Livestock numbers were not modified in response to fire events.

Table 3. Tree basal area and livestock carrying capacity for different vegetation states in Scenario 2: Remnant eucalypt savanna-woodland in north Queensland

	Tree basal area at 30 cm height (m^2/ha)	Livestock carrying capacity (AE/ha)
Initial tree basal area	11.34	0.057
50 years of thickening	13.57	0.039
Thinned <10 cm DBH	10.06	0.064
Thinned <20 cm DBH	7.76	0.082

Calculation of net CO_2-e stock

All stocks and emissions (Table 1) were converted to carbon dioxide equivalents (CO_2-e). The net CO_2-e stock (Eqn 1) was calculated in an annual time-step and is a function of the carbon stock present on-farm (Eqn 2) minus non-biomass emissions (e.g. livestock methane and fuel use) up to that year in the scenario (Eqn 3).

$$\text{Net } CO_2\text{-e stock}_i = \text{carbon stock}_i - \text{non-biomass change emissions}_i \quad (1)$$

where i = year since start of scenario.

$$\text{Carbon stock}_i = \text{live tree biomass}_i + \text{dead standing tree biomass}_i + \text{coarse woody debris}_i + \text{woody clearing debris}_i + \text{forage and litter biomass}_i + \text{soil carbon}_i + \text{livestock carbon}_i \quad (2)$$

where i = year since start of scenario. Table 1 provides more details on the calculation and source of data for individual terms used in the equation.

$$\text{Non-biomass change emissions}_i = \sum_{j=1}^{i} \text{livestock methane} + \sum_{j=1}^{i} \text{soil non-}CO_2\text{ emissions} + \sum_{j=1}^{i} \text{savanna burning} + \sum_{j=1}^{i} \text{clearing fuel emissions} + \sum_{j=1}^{i} \text{general property emissions} \quad (3)$$

where i = year since start of scenario and j = year 1. Table 1 provides more details on the calculation and source of data for individual terms used in the equation.

Calculating the current carbon stock in an annual time-step eliminates the need to calculate net ecosystem productivity and finer-scale plant and soil respiration and CO_2 capture through photosynthesis. However, an understanding of a systems limits is required (e.g. Tables 2, 3) to ensure predicted carbon stock changes are possible.

Results

Scenario 1: Twenty-year-old brigalow regrowth

The analysis indicated that over 50 years, the retaining regrowth strips option offset 80% of livestock methane and clearing emissions (emitted 5.8 t CO_2-e/ha), whereas clearing all regrowth emitted 42.8 t CO_2-e/ha (Fig. 1). The retain regrowth treatment accumulated 71.5 t CO_2-e/ha over 50 years. However, there was negligible livestock carrying capacity for half the period.

Scenario 2: Remnant eucalypt savanna woodland (RESW)

The analysis indicated that over 50 years, retaining the current woodland structure emitted 7.4 t CO_2-e/ha (Fig. 2), of which 96% was livestock methane. The thickening option accumulated 20.7 t CO_2-e/ha with a livestock carrying capacity decline of 30%. The thinning treatments were assumed to recover to the original stand density before retreatment, therefore, carbon storage varied depending on the stage in the regrowth cycle. Thinning trees <20 cm DBH initially killed 30 t CO_2-e/ha of trees, however, with the relatively slow decomposition and subsequent regrowth the treatment only emitted 12.4 t CO_2-e/ha at the end of the 50 year analysis with a maximum of 20 t CO_2-e/ha emitted during the simulation. Thinning trees <10 cm DBH had a maximum accumulated emission of 8.9 t CO_2-e/ha at the end of the 50 year analysis. Live and dead vegetation carbon stocks were on average 1 and 4% lower for the <10 and <20 cm thinning treatments than 'retaining the current woodland structure' option after 50 years. The livestock carrying capacity fluctuated with the stage of regeneration following thinning. The mean livestock carrying capacity over the 50 year period was 7 and 22% higher for the <10 and <20 cm thinning treatments, respectively, compared with retaining the current woodland structure.

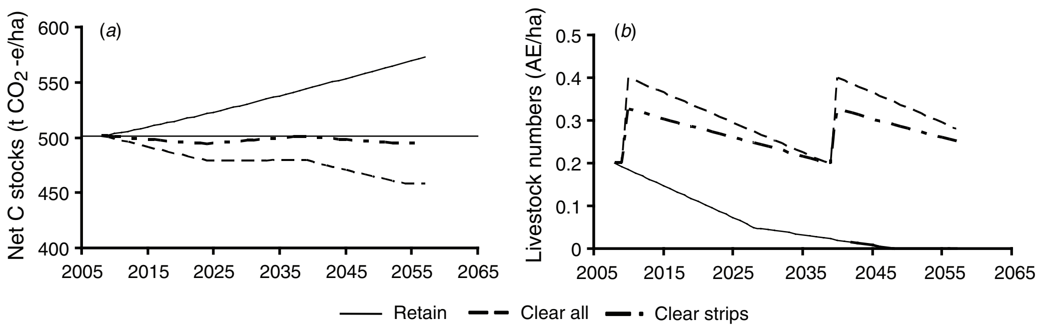

Fig. 1. Impact of three alternative management options for Scenario 1 '20-year-old brigalow regrowth' (retain regrowth, clear all regrowth, and clear regrowth strips) on (*a*) net carbon stocks (stocks minus emissions) and (*b*) livestock numbers.

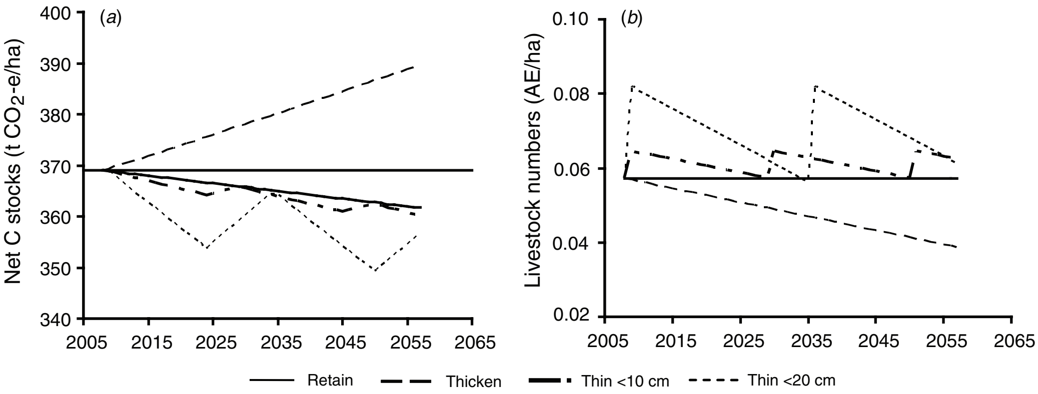

Fig. 2. Impact of four alternative management options for Scenario 2 'remnant eucalypt savanna-woodland' (retain current woodland structure, allow woodland to thicken, thin trees <10 cm DBH and thin trees <20 cm DBH) on (*a*) net carbon stocks (stocks minus emissions) and (*b*) livestock numbers.

Discussion

These analyses have indicated the potential scope for grazing businesses to have an impact on their 'greenhouse' outcome based on the choice of future management options (range 71.5 t CO_2-e/ha sequestered to 42.8 t CO_2-e/ha emitted; Fig. 1). However, an improved greenhouse outcome through manipulation of woody vegetation is often associated with a reduction in livestock carrying capacity owing to competition between edible herbaceous growth and largely inedible woody plants (Scanlan 2002). Nevertheless, opportunities may exist to encourage greater tree density on less productive or degraded areas, design spatial arrangements that minimize the impact of trees on forage production or exploit the often improved nutritional value of forage on offer under trees (McKeon *et al*. 2008).

Although outside the scope of this paper, the economic implications of the management options should be assessed as part of whole business management decisions. This analysis would need to include a range of prices for carbon, livestock and management operations (e.g. thinning costs) and a selection of the likely rules imposed by potential future trading schemes to determine the optimum balance for a grazing business. A key assumption would be that accumulation of carbon or avoidance of emissions somewhere in the grazing business (e.g. woody vegetation or soil) will be recognised as an offset for emissions elsewhere in the business (e.g. livestock methane). This will be a challenge for the livestock industries and policy makers to work through in the coming years.

Many assumptions were required in this analysis to predict the response of each carbon stock, flux or emission to alternative management options. Key components where assumptions are likely to have a significant impact on the budget outcome include the following:

(1) predicting growth rates and decay of vegetation biomass. The growth rate of regrowth particularly in different regions and after different clearing treatments is poorly understood, with current datasets predicting a substantial difference in growth rates in similar vegetation types (e.g. Scanlan 1991; Bradley 2006). The upper limit of biomass accumulation and the effect of intermittent droughts and climate change are also largely unknown at the property scale. Initial investigations have been undertaken on the dynamics of standing dead biomass, coarse woody debris and clearing debris over time (Burrows *et al*. 2002; Fensham 2005); however, many questions still remain at the woodland stand scale particularly regarding longevity following different clearing methods. These carbon stocks may have potential to be exploited as their longevity is sensitive to management (e.g. fire control) and their presence is not reliant on limited resources such as soil water which drive forage and tree growth;

(2) soil carbon dynamics. Soil carbon is the major carbon stock on grazing land, contributing 90% of the carbon stock in the brigalow regrowth scenario and 60% in the eucalypt remnant savanna-woodland scenario. Unfortunately, there is little data on how soil carbon responds to various management practices in grazing land. Harms and Dalal (2003) demonstrated a variable, though generally declining soil carbon stock following clearing of remnant vegetation. However, the response of soil carbon to different clearing techniques, clearing regrowth, allowing regrowth to grow or allowing remnant woodlands to thicken requires more investigation. The soil carbon response to grazing management also requires further study as preliminary studies indicate variable and sometimes counter-intuitive results (e.g. Ash *et al*. 1995; Carter and Fraser 2009). No change in soil carbon was assumed for this exercise based on moderate to conservative grazing management (matching average annual forage production to stocking rates), however, if the soil carbon stock (in t CO_2-e/ha) increased by 5% over 50 years in the brigalow regrowth scenario (23.7 t CO_2-e/ha), the retain regrowth strips option would sequester 19.2 t CO_2-e/ha rather than emit 4.5 t CO_2-e/ha. Alternatively if grazing management leads to a reduction in soil carbon the impact is likely to be substantial;

(3) livestock methane. Livestock methane is a widely discussed cumulative emission from grazing businesses and, therefore, accurate estimates are required for a property-scale budget. Kennedy *et al*. (2007) have developed a preliminary model for northern Australia to estimate emissions for different regions, land-types and herd management.

However, key inputs are currently uncertain for many situations and further work is required. Public calls to substantially reduce livestock methane emissions and as a consequence livestock numbers have potential to significantly reduce the profitability of grazing businesses with flow-on impact on the socio–economic balance of regional areas in northern Australia;

(4) soil non-CO_2 emissions. Soil non-CO_2 emissions were assumed zero in this analysis primarily due to lack of data in the case study regions and no information on the response to the management options used in this study. However, Dalal and Allen (2008) in a global review of data from tropical savannas, reported a mean sink of –0.02 t CO_2-e/ha for methane, and a mean emission of 0.28 t CO_2-e/ha for nitrous oxide (total emission 0.26 t CO_2-e/ha). This would equate to an emission of 13 t CO_2-e/ha during the 50-year scenarios across all management options, which is almost double the livestock methane emissions in the relatively low productivity remnant eucalypt savanna-woodland scenario. Soil emissions are likely to continue even with livestock destocking. The magnitude of soil emissions and the extremely limited dataset for northern Australia highlights the need for more research in this area.

An analysis of uncertainty was not attempted in this assessment primarily due to the lack of appropriate available data. Progression of these analyses into the standardised life cycle assessment methodology (e.g. Harris and Narayanaswamy 2009) would require substantial effort to adequately capture an estimate of uncertainty.

Conclusion

The global 'carbon economy' means that grazing businesses will have media and possibly political pressure applied to consider the balance between their greenhouse gas impact and grazing productivity. A property-scale greenhouse gas budget is one tool to understand and demonstrate the greenhouse gas impact of the current business and assess alternative management options. Access to reliable property-scale methodology to measure current carbon stocks and greenhouse gas emissions and the ability to predict change with management, particularly soil carbon, livestock methane and vegetation biomass will be essential.

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